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The Ouachita System

PETER T. FLAWN, AUGUST GOLDSTEIN, JR.,

PHILIP B. KING, AND C. E. WEAVER

BUREAU OF ECONOMIC GEOLOGY

THE UNIVERSITY OF TEXAS, AUSTIN

PETER T. FLAWN, *Director*

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

SAM HOUSTON

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

MIRABEAU B. LAMAR

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THE OUACHITA SYSTEM

PETER T. FLAWN,[1] AUGUST GOLDSTEIN, JR.,[2]
PHILIP B. KING,[3] and CHARLES E. WEAVER[4]

Abstract

PETER T. FLAWN

This publication analyzes available surface and subsurface data on the largely concealed Ouachita system and interprets the stratigraphy, tectonics, and history of the geosyncline and deformed belt. It is a joint undertaking by four authors on various parts of the system and aspects of its development. The publication is introduced by a general statement of the problem, an explanation of the method of attack and the nature and extent of industry cooperation, a discussion of petrographic, stratigraphic, and structural nomenclature, a discussion of the present surface of Paleozoic and metamorphic rocks, and a summary of the fossil record. The terms incipient, very weak, weak, and low-grade metamorphism are defined by mineralogical parameters.

The name Ouachita system is applied to a belt of deformed Paleozoic rocks which borders the southern edge of the Central Stable Region of North America in the same way that the Appalachian system borders the eastern edge. The deformed rocks of the Ouachita belt are known to extend from a point in east-central Mississippi westward and southward along a sinuous course into Mexico, but in the more than 1,300 miles of known length of the system a strike length of only about 275 miles is exposed. Except in Mexico, the interior parts of the system have subsided deeply beneath younger sedimentary rocks of the Gulf Coastal Plain, and outcrop and borehole data are available only for a relatively narrow strip of the belt adjoining the foreland (maximum width about 80 miles), but detailed studies of the stratigraphy and tectonics permit inferences concerning the parts of the system beyond the down-dip limit of well control.

The Ouachita Mountains, from which the system derives its name, are in a major structural salient of the deformed belt and are composed of a thick folded and faulted sedimentary sequence of distinctive facies —Ouachita facies. This includes relatively thin lower Paleozoic dark graptolitic and siliceous shales, cherts, sandstones, and limestones, and a relatively thick upper Paleozoic dominantly clastic sequence which includes deep-water turbidite deposits. The important change in stratigraphic character of the sequence occurs between Arkansas novaculite and Stanley shale and took place in Early or Middle Mississippian time. Ouachita Mountain rocks are strongly folded, broken by reverse faults, and thrust northward or northwestward along a series of low-angle faults. Strike-slip movement of the mass took place along transverse faults bordering the Arbuckle buttress. Along the northern front of the Ouachita Mountains, foreland (Arbuckle) facies rocks as well as rocks of transitional facies occur within the deformed belt, so that the facies boundary and the tectonic boundary are not coincident. Incipient to low-grade metamorphism occurs along the axis of the Broken Bow–Benton uplift, an anticlinorium that forms the central part of the range, and in other areas along loci of strong deformation.

In the Marathon Basin, similarly located within a structural salient of the Ouachita

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system, rocks and structures are exposed that are remarkably similar to those of the Ouachita Mountains, differing only in structural scale and lack of metamorphism. Both areas are characterized by a pronounced negative gravity anomaly. Likewise, in both areas stratigraphic studies indicate that clastic rocks are more abundant southward and that clastic rock units thicken in the same direction. In the Ouachita Mountains, Marathon Basin, and in other exposures of the belt in Persimmon Gap and the Solitario in Trans-Pecos Texas, the lower Paleozoic rocks are raised along thrust faults and in complexly faulted anticlinoria.

Rocks of similar facies and with the same kind of deformation are recognizable in well cores and samples taken from the concealed Texas segment of the belt between the Ouachita Mountains and the Marathon Basin. Lower Paleozoic rocks of Ouachita facies form the subcrop in disconnected areas along the front of the belt and within it. These probably indicate structurally high areas along faults and anticlinal axes similar to those observed in the areas of outcrop. Ouachita Mountains lithologic units and structures can be traced in the subsurface as far south as central Texas; Marathon Basin lithologic units and structures can be traced eastward and westward in subsurface for some tens of miles. Belts of rocks with no outcrop equivalents have been penetrated by wells within the concealed Texas segment; these include dark clastic rocks, metasedimentary rocks, metavolcanic rocks, and partly mylonitized granitic rocks. Zones of metamorphism of different character and intensity cross lithologic boundaries.

Rocks and structures of the Ouachita Mountains pass eastward beneath coastal plain deposits and follow a southeasterly course into Mississippi. Data on this segment of the system are scanty, and lithologic units and metamorphic zones have not been mapped in as much detail as in the Texas segment. Here gross lithologic-tectonic units include a frontal belt of deformed upper Paleozoic rocks and the extension of the Broken Bow–Benton uplift. The junction with the Appalachian system in Alabama is complex. Deformed lower Paleozoic carbonate rocks in the Valley and Ridge province of the Appalachian system bend sharply northwestward and constitute a northwest-trending subcrop belt in Alabama and Mississippi. Interior zones probably cross each other complexly without either system clearly overriding or being overridden by the other.

In northern Mexico scattered outcrops of pre-Mesozoic rocks and a few boreholes indicate a Paleozoic tectonic land, now largely concealed, where deformed and metamorphosed belts of sedimentary rocks are intruded by granitic material. In this area, the interior part of the Ouachita system did not subside so deeply as in Texas and the southeastern states, perhaps because of more extensive introduction of granitic material into the crust.

Metamorphism in the Ouachita system is of two types: (1) incipient to weak metamorphism, largely dynamic, distributed irregularly within the frontal zone of the belt, for the most part along the axes of major structures and along loci of strong deformation, and (2) low- to medium-grade regional metamorphism with a strong shearing component forming a broad band in the interior zone. Several periods of metamorphism are indicated: (1) an older regional metamorphism entirely within the interior part of the system and accompanied by emplacement of numerous quartz veins; (2) a later (pre-Atoka) low-grade high-shear metamorphism which accompanied dislocation and thrusting of the interior zone toward the craton; this metamorphism locally effected retrograde metamorphism, mylonitization, and phyllonitization, breaking the earlier formed quartz veins and converting them into augen; (3) post-Atoka metamorphism, mostly along deformation axes in the frontal zone of the system.

Several wells have penetrated post-orogenic rocks of late Paleozoic age, mainly red beds, lying in structurally low areas within the deformed and metamorphosed terrane.

The Ouachita system is bordered on the north by various positive and negative structural elements lying within or along the edge of the craton. These include (1) older positive elements that influenced the location of the geosyncline and the course of the subsequent deformed belt and include such elements as the Ozark, Llano, and Devils River uplifts, and (2) subsequently formed late Paleozoic uplifts and basins which resulted from the general mobility of the craton during the late Paleozoic orogeny; these include the frontal basins which border the Ouachita belt from Mississippi to Mexico and features such as the Muenster uplift and Fort Stockton high or Pecos arch. The Arbuckle element, which formed a buttress against the thrust of the Ouachita system, is not a simple epeirogenic uplift—its rocks were deformed and raised during an independent intra-cratonic orogeny.

X-ray studies of shales within and adjacent to the Ouachita belt support petrographic observations as to the degree of alteration. A new measurement, sharpness ratio (SR), appears to be a valid tool for determining degree of metamorphism in slates and shales.

Two tectonic provinces are recognized within the Ouachita system: (1) a frontal zone bordering the craton where deformation was by flexure, analogous to the Valley and Ridge tectonic province of the Appalachian system, and (2) an interior zone where deformation was mainly by shear, analogous to the Blue Ridge tectonic province of the Appalachian system. The boundary between these two provinces, the Luling front, is marked by very highly sheared rocks, locally mylonitized, and probably is a zone of complex thrust faulting. The frontal zone is broadly developed in the Ouachita and Marathon salients, which do not appear to be typical of the system as a whole. Within the salients the frontal zone of the belt is much wider than in the concealed segments and contains younger rocks. Probably the areas of the salients remained actively negative and received sediments through Atoka time while other parts of the belt were emerged. The subcrop pattern of rock units suggests that the entire area of the Ouachita Mountains is a complexly deformed synclinorium, a concept which is supported by gravity data. In the area of the Devils River uplift, the rocks of the interior zone have overridden an attenuated or telescoped frontal zone, and rocks of foreland facies mantling the uplift are strongly deformed and slightly metamorphosed. Frontal overthrusts with a minimum displacement of 8 to 10 miles occur along the course of the Ouachita belt. They have been mapped on the surface in some areas, proved by drilling in others, and inferred from subcrop geology in others.

Gravity data show a pronounced minimum along the course of the frontal zone, suggesting it is a thick body of sedimentary rocks. Gravity patterns in the interior zone are more complex, with disconnected maxima which may represent bodies of differing lithologies, possibly intrusive bodies.

The early history of the belt is difficult to reconstruct because little is known about the southern margin of the craton in Precambrian time. Extensive late Precambrian volcanic activity north of the developing Ouachita belt is indicated by rhyolitic lavas and pyroclastic rocks extending from New Mexico to Oklahoma. Resistant massifs, such as the Llano and Devils River uplifts, probably influenced the zone of subsidence of the early phase of the Ouachita geosyncline. The oldest rocks exposed in the salients are Late Cambrian but the nature of the deformation suggests that they are underlain by a thick body of sedimentary rocks which may include late Precambrian sedimentary rocks in the lower part. Early Paleozoic rocks are thin widespread argillaceous and siliceous rocks with a few clastic wedges and are characterized by a pelagic fauna. Rock and faunal facies are remarkably persistent, and thin units represent long time intervals. These deposits are not clearly miogeosynclinal or eugeosynclinal but have more of the attributes of a "starved" eugeosynclinal deposit; they are in many ways similar to the leptogeosynclinal deposits in some Alpine basins which are starved orogenic basins. However, they also show many of the features of shallow-water deposition. The abundant silica may have been derived from volcanic ash emanating from more mobile parts of the belt to the south. Sandstone wedges which thicken to the south suggest that there were early Paleozoic orogenic movements. A drastic change in sedimentation occurred in Early Mississippian time when the mobile part of the belt moved toward the craton. Thick deposits of Late Mississippian and Early Pennsylvanian clastic rocks were dumped into long narrow restricted basins. These are mainly sandstone and shale but also include tuff, siliceous shale, and remarkable boulder beds. In part, these sediments were deposited in deep water, being transported by turbidity currents from rapidly rising tectonic lands within the system.

The orogenic phase overlapped the geosynclinal phase. In the eastern part of the belt the deformation was mainly Pennsylvanian, but to the west it began later and continued into Early Permian time, or even later in Mexico. With the orogenic movements came a rearrangement of depositional patterns and a creation of new basins along the front of the belt bordering the foreland. No rocks younger than Atoka occur in the Ouachita Mountains, and the mountains were probably an area of active deformation and erosion during Des Moines time; the detritus was deposited in the new basin created through the northward shift of depositional axes. Depositional environments changed from deep water to shallow as the new basin filled and downwarping ceased.

In the eastern part of the Ouachita system the final orogenic phase began in Atoka and continued at least through Des Moines time as rocks of that age in the basin north of the system are thrown into linear folds parallel to those in the Ouachita belt. The final movement culminated in frontal overthrusting and lateral movements along the flanks of the Arbuckle buttress.

In the western segment the last orogenic phase is dated by conglomerates in the middle of the Gaptank formation as beginning in Missouri time. Frontal overthrusts occurred in Early Permian time but before deposition of the type Wolfcamp sequence. Lower Paleozoic Ouachita facies rocks moved over foreland basin rocks along the frontal overthrust. Southwestward in Mexico deformed Permian sequences contain tectonic sediments and lavas and are intruded by granitic rocks. Orogeny in this area continued into late Permian time or possibly later.

In the post-orogenic phase the salients were raised by epeirogenic movements while the rest of the system continued to subside beneath younger sedimentary rocks. Post-orogenic sedimentary rocks, mostly red beds, are preserved in structurally low areas in local basins within the interior part of the belt.

Possibilities for oil and gas production are summed up as follows: (1) Ouachita facies rocks—poor, except for possible accumulations in fractured rocks where they have been juxtaposed with possible source beds; (2) late Paleozoic foreland facies rocks in basins along the front of the Ouachita belt—fair; although most sandstones are argillaceous and quartzitic, Atoka sandstones in the McAlester basin contain commercial gas accumulations; there are also possibilities in areas favorable for reef development; (3) early Paleozoic foreland facies rocks adjacent to the Ouachita belt or beneath allochthonous plates of Ouachita facies rocks—good, where rocks are platform facies rather than trough or deep-basin facies.

Introduction

PETER T. FLAWN

General Statement

The name Ouachita system is applied to a belt of deformed Paleozoic rocks which borders the southern edge of the Central Stable Region of North America in the same way that the Appalachian system delimits the eastern margin of the stable area. Rocks and structures of the Ouachita system, however, are not as well exposed as those of its eastern analog. The largest area of exposure of the deformed belt is the Ouachita Mountains of eastern Oklahoma and western and central Arkansas where folded and faulted rocks ranging in age from Cambrian(?) to Middle Pennsylvanian (Atokan) form a series of parallel ridges and valleys over a strike distance of 220 miles. The total area of the Ouachita Mountains exceeds 12,000 square miles. The only other major exposure of the Ouachita system is in Trans-Pecos Texas where the Marathon uplift provides excellent exposures of highly deformed thrust-faulted Paleozoic rocks over a strike distance of nearly 50 miles; orogenic movements in this area involved rocks ranging from Cambrian through Pennsylvanian and probably Early Permian (Wolfcamp) age. There are other smaller exposures of the deformed belt west and south of the Marathon area in the Solitario uplift and near Persimmon Gap in Brewster County, Texas, and at the base of the Sierra del Carmen southeast of the town of Boquillas in Coahuila, Mexico. In Burnet County in central Texas, a glimpse of steeply dipping rocks of the belt can be seen in Cypress Creek and the Turkey Bend area during periods of low water in Lake Travis.

Thus the total length of exposed parts of the belt is not more than 275 miles. Between the widely separated exposures in Oklahoma-Arkansas and Texas and eastward from the outcrops in Arkansas, the course of the Ouachita system has been outlined by boreholes and by geophysical observations. It is now known that rocks and structures of the Ouachita system extend nearly 1,300 miles from the Rio Grande in Texas to a point in western Alabama only 60 miles from where the Appalachian folds disappear beneath the coastal plain (P. B. King, 1950, fig. 1; 1951, p. 149; this report, pp. 83–98). It is much more difficult to trace the Ouachita system southward into Mexico because exposures of Paleozoic rocks are widely separated, only a few wells penetrate the thick cover of Mesozoic rocks, and this area was strongly deformed during Laramide orogeny. Although data are insufficient to determine the nature and trend of the structures of the belt in Mexico, north-central and northeastern Mexico was probably a Paleozoic tectonic land and the Paleozoic orogenic belt probably extended at least 300 miles south of the Rio Grande, and perhaps farther (Flawn and Díaz G., 1959). The eastward extension of the Ouachita system in the subsurface poses one of the major problems in North American structural geology. The trends of the Ouachita and Appalachian systems, as projected and defined by drilling, meet in the subsurface at an acute angle. A number of possible interpretations of this junction have been outlined by P. B. King (1950, pp. 666–669; this report, pp. 97–98). Several geologists have discussed in a general way the possibility that the Ouachita system crosses the Appalachian system and continues southeastward into Florida (P. B. King, 1950, pp. 666–667; Woods, 1956, p. 7; Applin, 1956, personal communication to P. B. King); there is some geophysical evidence to support this concept (Woollard, 1955, p. 1638; Woods, 1956, p. 7; E. R. King, 1959, p. 2853). In a previous paper, Flawn (1959b, p. 24) gested that the Ouachita system was deflected around the end of the southwest-plunging Appalachian structures in a sharp structural recess and continues southeastward into Florida. P. B. King (this report, p. 97) believes that the two systems are parts of an originally continuous belt of deformation and suggests that their junction may be comparable to the extremely complex junctions observed within island arc systems where trends cross each other but do not continue very far beyond the intersection.

The Ouachita system is concealed for 80 percent of its proved length, and those parts that are exposed are structural salients along the frontal margin of the belt; information from wells is likewise largely restricted to that part of the belt bordering the foreland. The interior parts of the Ouachita system have been depressed beneath the great thicknesses of sedimentary rocks in the Gulf Coastal Plain and the Mississippi embayment. Those wells which have encountered the more deeply buried parts of the deformed belt south and east of the front penetrated highly sheared metasedimentary rocks, mostly phyllite and phyllitic metaquartzite. Several of the more southerly wells found fine-grained mica schist, locally garnetiferous, and at the western end of the belt phyllitic marbles are common. In southwest Texas, in Bexar and Medina counties, partly mylonitized granitic rock and altered volcanic rock have been penetrated. These wells provide tantalizing glimpses of an orogenic belt that is the foundation of at least the inner part of the Gulf Coastal Plain and which is probably much more extensive. The linear extent of the Ouachita system and what little can be seen of its rocks and structures suggest that it is a major orogenic belt, most of which is completely buried. From the structural front of the belt to the downdip limit of well control is about 50 miles. This includes an outer zone approximately 35 miles wide where unmetamorphosed and very weakly metamorphosed rocks are folded, faulted, and thrust against and over the foreland, and part of another tectonic unit composed of highly sheared low-grade metamorphic rocks characterized by well-developed foliation, slaty cleavage, and fracture cleavage.

In the classic picture of an alpine-type deformed belt, three major zones have been recognized (Bucher, 1955, pp. 348–362): (1) an outer belt of folded and thrust-faulted rocks where the deformation is surficial; (2) a marginal belt of "peel" thrusts and piled up nappes wherein the basement is involved in the deformation; and (3) an inner belt characterized by deep crustal folds and metasomatism. In the southern Appalachians (P. B. King, 1950, pp. 638–656; Bucher, 1955, pp. 360–361), the Valley and Ridge province corresponds to zone (1), the Blue Ridge province is analogous to zone (2), and the metamorphic and plutonic Piedmont belt (including the eastern part of the Blue Ridge province) represents zone (3). The distance from the Allegheny front of the Valley and Ridge province to the Blue Ridge front is approximately 40 miles; the Blue Ridge thrust belt has similar width. To the southeast the core of metamorphic and plutonic rocks is at least 120 miles wide to where it is concealed by overlapping Coastal Plain deposits. If the Appalachian system is bilaterally symmetrical (P. B. King, 1950, p. 655), it must be considerably more than 200 miles wide with concealed marginal and outer zones south and east of the metamorphic and plutonic belt.

If the Ouachita and Appalachian systems are compared (and it seems advisable to compare the two great Paleozoic orogenic systems of the North American continent), the Ouachita system shows, in outcrop and borehole, an outer or frontal zone of unmetamorphosed to very weakly metamorphosed folded and thrust-faulted rocks similar structurally to that of the Appalachian Valley and Ridge province, and the edge of an interior zone wherein phyllite, slate, and metaquartzite show well-developed foliation, slaty cleavage, and fracture cleavage very similar to rocks of the Blue Ridge province. The boundary between the frontal and interior zones of the Ouachita belt is herein named the Luling front. Nowhere, however, has there been found a well-defined core of metamorphic and plutonic rocks comparable to the Appalachian Piedmont. A few of the most southerly wells encountered metamorphic rocks of medium grade containing garnet and amphibole that suggest the presence of a more highly metamorphosed terrane in this direction, but well control is inadequate to fix boundaries. If the Ouachita system is a first-rank orogenic belt, its core must lie south and east of the known part beneath the thick prism of Coastal Plain sedimentary rocks; if the Ouachita system is symmetrical the hidden core is flanked by marginal and outer zones still farther south.

Within the known part of the structural belt is a large body of rocks of distinctive facies—Ouachita facies—as well as rocks of foreland facies, rocks of transitional facies, metamorphic rocks, and igneous rocks. Rocks of Ouachita facies include thick upper Paleozoic geosynclinal and post-orogenic deposits and a lower Paleozoic sequence of siliceous rocks and dark fine-grained clastic rocks that is not particularly thick where exposed or penetrated by wells.

Purpose and Scope of the Report

This report on the Ouachita system is an outgrowth of studies of the Texas and southeast New Mexico basement which began in 1950. During these studies the writer examined many cores and cuttings from wells that penetrated the metamorphosed part of the Ouachita structural belt. Obviously the Ouachita structural belt posed so many important tectonic problems that it ranked as a major problem in its own right and deserved more than a chapter in a publication on the Precambrian basement. Consequently, when results of the Precambrian basement study were ready for publication, a new project on the Ouachita structural belt was formulated. As the study depended largely on information from wells, the major oil companies operating in Texas were consulted to determine the extent of their interest. Without industry cooperation a regional subsurface study would not have been possible. The companies concerned with oil exploration in Texas proved to be very much interested in encouraging a project on the Ouachita structural belt and cooperated by furnishing well samples and stratigraphic information.

The main objectives of the project were (1) to develop the broad tectonic pattern within the deformed belt, (2) to evaluate the economic potential of its frontal structures, and (3) to assess its role in the structural development of the North American continent.

Early in the course of the work it became apparent that it would be desirable to study the whole of the Ouachita belt rather than merely the Texas segment and to include the results of X-ray studies of the shales of the Ouachita system. Invitations to coauthorship were extended to August Goldstein, Jr., Philip B. King, and Charles E. Weaver. Their participation in the project has made it possible to present a unified picture of the Ouachita system. Authorship of the various chapters of the report is shown on pages iii–vi.

Cooperation with Industry

The first step in securing the cooperation of operating oil companies in the Ouachita structural belt project was a letter from the Director of the Bureau of Economic Geology, the late John T. Lonsdale, addressed to company geologists and executives, which outlined the proposed project and invited suggestions. Following unanimous expression of interest, the project was officially started. Implementation of cooperation was left to the companies; some appointed a contact man for the project, generally a staff or research geologist; others left the mechanics of cooperation to district or division geologists. Both methods were successful, inasmuch as both provided a free interchange of information between the Bureau of Economic Geology and the company. Throughout the course of the project, preliminary results were made available to all. Geologists from many companies visited the Bureau of Economic Geology to discuss the work and the general problems. This research project is thus an illustration of successful voluntary cooperation between industry and a State agency.

Previous Work

Development of geological thinking about the Ouachita structural belt records the work of distinguished geologists of two generations. From about 1800 to 1887, reports on the Ouachita Mountains in the Arkansas Territory, later the State of Arkansas, and the Indian Territory, later the State of Oklahoma, were limited to the observations of explorers who made geological reconnaissances and mineral surveys (Honess, 1923, pp. 27–31). In 1887 and thereafter, geologic mapping was undertaken in Arkansas by T. B. Comstock (1888), L. S. Griswold (1892), R. A. F. Penrose (1892), J. C. Branner (1896, 1897), G. H. Ashley (1897), N. F. Drake (1897), A. H. Purdue (1909a, 1909b, 1910), and Purdue and Miser (1923). J. A. Taff (1901a, 1901b, 1902, 1903) made the first geological map of the western and northern Ouachitas of Oklahoma following an earlier reconnaissance by R. T. Hill (1891). A bibliography of earlier geological publications on Arkansas geology is given by J. C. Branner (1909).

Modern study of the geology of the Ouachita Mountains began with the work of H. D. Miser who, in his earlier studies, was guided by A. H. Purdue (Purdue and Miser, 1923; Miser and Purdue, 1918, 1929; Miser, 1921, 1929, 1931, 1934a, 1934b, 1934c, 1943; Miser and Honess, 1927); Miser's research laid a broad foundation for all subsequent work. At approximately this same time a great contribution to the geology of the Ouachita Mountains in Oklahoma was made by Honess (1923, 1924, 1927). More recent mapping and stratigraphic interpretation have been contributed by Harlton (1934, 1938, 1947, 1953), Hendricks (1943), Hendricks and Goldstein (1953), Hendricks et al. (1947), Pitt (1955), Tomlinson and Pitt (1956), Cline (1956a, 1956b, 1960), Misch and Oles (1957), and Shelburne (1960). Mapping by the U. S. Geological Survey Fuels Branch is currently under way in Arkansas (Reinemund and Danilchik, 1957). Petrography of Ouachita Mountains sedimentary rocks has been described by Honess (1923), Goldstein and Reno (1952), Goldstein and Hendricks (1953), Harlton (1953), Bokman (1953), and Goldstein (1959a, 1959b). In 1959 the geology of the Ouachita Mountains was the subject of a symposium volume prepared by the Dallas and Ardmore Geological Societies and including papers by Branson, Cline and Shelburne, Decker, Elias, Flawn, Goldstein, Ham, Harlton, Hendricks, Howell and Lyons, Laudon, Miser, Pitt, Scull, Scull et al., and Tomlinson.

Far to the southwest, in the Marathon Basin of Brewster County, Texas, steeply dipping Paleozoic strata of the Ouachita structural belt came to the attention of early reconnaissance geologists such as Von Streeruwitz (1891), Hill (1900), Udden (1907a, 1907b), and Baker and Bowman (1917). In 1929, P. B. King started work in the Marathon Basin; his field work continued through 1931 and resulted in a classic U. S. Geological Survey Professional Paper (King, 1937). More recent investigations in the Marathon Basin have been carried out by Adams and Frenzel et al. (1952); J. L. Wilson (1956a, 1956b), Hall (1956), Fan and Shaw (1956), Berry and Nielsen (1958). Geologic studies in the Solitario area southwest of the Marathon Basin have been made by Baker and Bowman (1917), Powers (1921), Sellards, Adkins, and Arick (1931), Lonsdale (1940), and Herrin (1959); Paleozoic rocks in the Persimmon

Gap area were described by Maxwell et al. (1949, pp. 27–28), J. L. Wilson (1954a), Lonsdale et al. (1955, pp. 54–59 and map), Hazzard, Maxwell, and Lonsdale (1958), Berry and Nielsen (1958), and Maxwell et al. (MS).

Many contributions to the geology of the Ouachita system have been made through the efforts of paleontologists to solve problems of age and correlation. David White (1934) described the plants, C. E. Decker (1936), Ruedemann (1947), and Berry (1960) the graptolites, Henbest (1936) the radiolarians, Cooper (1931, 1935), Ellison (1941, 1946), Ellison and Graves (1941), Graves (1952), and Hass (1950, 1951, 1956) the conodonts, and J. L. Wilson (1954b) the trilobites.

For many years it has been known that wells drilled near the Balcones fault zone in Texas pass from Cretaceous rocks into a sequence of steeply dipping clastic sedimentary rocks showing varying degrees of incipient to weak metamorphism. The first published reference to these rocks was made by Udden (1919), who speculated as to their age. After more wells had been drilled, Powers (1928), Cheney (1929b), Miser (1929), Sellards (1930, 1931b), Miser and Sellards (1931), and Van der Gracht (1931a) were able to demonstrate that these rocks were related to folded rocks of Paleozoic age exposed in the Ouachita Mountains of Arkansas and Oklahoma and to those of the Marathon Basin of Texas. They outlined the extent of the folded belt and separated it from a hypothetical landmass, Llanoria, which was presumed to have provided the sedimentary material that filled the Paleozoic trough. The concept of Llanoria dates from before the turn of the century and is based on indications that the sedimentary detritus in the Ouachita belt came from the south (J. C. Branner, 1897, pp. 357–377; Miser, 1921, pp. 68–71; P. B. King, 1937, pp. 44, 54, 87–88). Miser (1921) and Sellards (1933) summarized the literature pertaining to Llanoria.

With new ideas on the processes of orogeny and the role of island arcs as source areas, the concept of Llanoria as an enduring landmass was modified (Van der Gracht, 1931a; P. B. King, 1950, pp. 663–668; H. J. Morgan, 1952; Flawn, 1956, pp. 58–61). Barnes (1948) studied some central Texas wells and outlined successive belts of increasing metamorphism from northwest to southeast; he interpreted the phyllites of the subsurface "schist ridge" of Caldwell County, Texas, previously thought to be Precambrian, as metamorphosed Paleozoic rocks. Goldstein and Reno (1952) extended Barnes' concept to include all metamorphosed sediments encountered in wells along the Luling-Mexia-Talco fault system. Kleihege (1948) studied metamorphosed sedimentary rocks in wells in Terrell and Val Verde counties, Texas, and concluded that they are of Paleozoic age. Masson (1955) and Woods (1956) distinguished and mapped several zones within the subsurface structural belt that are characterized by different degrees of metamorphism ranging from "semislate" to "fine-grained schist."

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METHOD OF STUDY

Nature of the problem.—The problem, simply stated, is to map the concealed Ouachita system.

Many of the complexly folded and faulted orogenic systems of the world that are exposed at the surface have been studied by geologists for decades and yet such is their complexity that many of their problems are still unsolved. It might seem thus overly ambitious to attempt a study of a concealed orogenic belt on the basis of merely several hundred randomly located boreholes. But from another viewpoint, such a study is comparable to reconnaissance geological studies of mountain systems during the 19th century; this project attempts to solve broad structural relationships and to map large-scale lithologic units through scrutiny of some scattered boreholes over a wide area. The interpretations of subsurface relations are supported by detailed studies of exposed parts of the structural belt, by geophysical data, by new techniques of rock analysis, and by a growing body of knowledge about the behavior and development of orogenic systems (Poldervaart, 1955).

Petrographic methods.—The most fruitful source of information is the rocks themselves. Therefore, as a first step, an attempt was made to locate and obtain cores and cuttings from all wells penetrating the Ouachita structural belt. Well samples were studied with a binocular microscope; selected samples were studied in thin section and/or by X-ray analysis.

Thin sections of cable tool or rotary cuttings do not give information on attitude of beds or larger structures, but through a long sequence of strata that have not been cored they provide a valuable record of mineralogy and texture that cannot be obtained otherwise.

Petrographic study of well cuttings, involving preparation of large numbers of thin sections, may appear a very laborious procedure compared to rapid studies of samples with the binocular microscope. However, inspection of sample logs of Ouachita facies rocks demonstrates that observations on degree of metamorphism and identification of rock types are commonly in error and have led to serious misinterpretations. The binocular microscope is not a reliable tool for study of weakly metamorphosed rocks. Metamorphic changes in the mineralogy and mineral structure of shales, sandstones, and carbonate rocks in the Ouachita belt (formation of new minerals of metamorphic origin, twinning, grain deformation, and elongation) may go undetected without thin-section study and too much importance may be given to cleavages and the sheen of second-cycle detrital mica. Hard, brittle shale with lustrous closely spaced partings may suggest a higher metamorphic grade than dull, compact, more massive shale, yet petrographic comparison of the two rocks might show that the lustrous shale has undergone no metamorphic change while the massive, dull shale is a partly reconstituted rock. In the Kinney-Val Verde-Terrell County area of southwest Texas, several wells (pp. 285, 303–311, 319–332) penetrate interlayered fine-grained calcite marble, dolomite marble, phyllite, and metaquartzite. The presence of calcite marble, phyllite, and metaquartzite in close association with the dolomite indicates that the entire sequence has experienced the same degree of low-grade metamorphism; this is obvious in the calcite marbles, phyllites, and metaquartzites, but the dolomites commonly show little indication of metamorphism. Calcite marbles show spectacular twinning and grain-stretching and are commonly rudely foliated; it is clear that they are completely recrystallized even without corroboration from bands of oriented quartz-sericite-muscovite and quartz-calcite mosaic. The dolomite, however, strongly resists deformation and displays a characteristic rhombic mosaic; in highly sheared dolomite there is seen locally an orientation of the long axes of the rhombs and rather obscure twinning, but only in the impure rocks where there are patches of deformed calcite grains and sericitic and quartzitic layers can it be clearly demonstrated that the dolomite has in fact experienced low-grade metamorphism.

This reluctance of fine-grained dolomite to display signs of metamorphism leads to misinterpretations in conventional binocular descriptions of the rocks where the observer notes metamorphism of the calcitic rocks and concludes that the dolomites are unmetamorphosed. The supposed change from metamorphosed to unmetamorphosed rocks is usually explained by faults or other structural discontinuities. In some wells these structural explanations appear correct, but petrographic scrutiny is necessary to verify them when they are based solely on supposedly "unmetamorphosed" or "normal" dolomite.

Petrographic methods can be applied to regional geologic problems of concealed basement or concealed orogenic belts to establish, within the limits of well control, major lithologic and tectonic divisions characterized by differing types and degrees of metamorphism, as well as zones of igneous activity and allochthonous plates. Petrographic methods provide a framework into which geophysical, geochemical, paleontologic, stratigraphic, X-ray, and surface mapping data can be fitted; they furnish information on the present physical state, history, and genesis of *the rock itself* that cannot be obtained by any other technique. For best results, the petrographic study should be regional in scope because the sample data from wells randomly spaced and commonly widely separated permit recognition of major features only. Insofar as possible, the petrographic work should be done by one individual, to eliminate variations in observational bias.

X-ray methods.—The X-ray is a tool of the mineralogist. Although it yields information on mineral composition and crystal structure, it does not furnish information on rock textures, structures, and mineral relations from which the history of a rock can be deciphered. It is nevertheless a valuable aid in the study of the very fine-grained rocks whose mineral composition defies resolution by standard petrographic methods.

One of the main problems in respect to the Mississippian-Pennsylvanian rocks of the Ouachita structural belt and its frontal basins is the discrimination between the different thick sequences of alternating sandstone and shale of the Stanley, Jackfork, and Atoka formations. Weaver (1958) has made extensive X-ray studies of the shales penetrated in the structural belt and the adjacent shelf and basin areas. He discovered that shales of foreland facies are characterized by interlayered illite-montmorillonite, whereas shales within the structural belt contain none. He also discovered a correlation between degree of metamorphism and a new measurement—sharpness ratio (SR) (p. 149). The X-ray technique is simple and involves no more than powdering the sample and determining the clay and mica minerals.

Collection of data.—In any regional subsurface study the first step is collection of well data, stratigraphic information, and samples. Most of the basic well data and stratigraphic information in this report were secured through correspondence with company geologists in various parts of Texas and Oklahoma, both in operating sections and in research laboratories, and through the cooperation of Petroleos Mexicanos in Mexico. Much additional information was obtained during visits with company geologists. Every effort was made to resolve conflicting information by checking back to original sources and by securing additional informed opinion in matters of interpretation. Inevitably, some conflicts had to be resolved by the writers' judgment.

Location and collection of well samples was a more difficult problem. Once the samples were found and the need for them was made known, they were in most cases generously shipped to Austin by the owner. Many geologists made a great personal effort to find missing samples. The Well Sample Library of the Bureau of Economic Geology contains samples of many wells which are not preserved in any other library; without the foresight of the founders of this library some 45 years ago, this study and others like it would not be possible.

NOMENCLATURE

Structural and Stratigraphic Nomenclature

Through geologic time, a major tectonic system, such as the Ouachita system or Appalachian system, passes through growth and change which produce a linear and commonly arcuate deformed belt or orogen. During geosynclinal development and the subsequent period of deformation, the system is a mobile belt. The mobile belt and the compressed, consolidated, and immobilized deformed belt are manifestations of fundamental processes of continental growth.

The name Ouachita system is applied to the southern tectonic system of the North American continent throughout its history; the earlier formed Ouachita geosyncline and Ouachita mobile belt and the product of the orogenic paroxysm, the Ouachita structural belt, are sequentially developed phases of the Ouachita system. The name Ouachita is taken from the major exposure of the deformed belt, and its application to the subsurface extensions of the belt seems straightforward and proper. In the literature other names have been applied to the deformed belt. Ouachita foldbelt and Ouachita-Marathon belt are clearly synonymous with Ouachita structural belt. The name Llanoria structural belt has been proposed by Masson (1955, p. 1593) and Woods (1956, pp. 3–11), but in the writer's opinion, perpetuation of the name Llanoria is not desirable. The name Marathon foldbelt has been used for the western limb of the belt in Texas; rocks and structures of the Ouachita structural belt in the Marathon uplift can best be considered as the Marathon salient of the Ouachita structural belt inasmuch as the continuation of the Ouachita structural belt westward around the Llano uplift is no longer in doubt.

Many misunderstandings have arisen in regard to the term Ouachita facies. This term properly refers to rocks lithologically and faunally like those exposed in the Ouachita Mountains and unlike rocks in frontal basins and shelf areas on the foreland. Rocks of Marathon facies are lithologically and faunally similar to those exposed in the Marathon region. These are remarkably similar to Ouachita facies rocks and may be called Ouachita facies, although they also show some foreland characteristics. In other areas along the front of the belt there are rocks even more clearly transitional between Ouachita and foreland facies.

An erroneous belief has arisen that all Ouachita facies rocks are metamorphosed and/or siliceous and that the term Ouachita facies implies metamorphosed and/or siliceous rocks. Some Ouachita facies rocks have experienced varying degrees of metamorphism but some are unmetamorphosed. The following distinctions are pertinent: (1) rocks of Ouachita facies, (2) rocks of foreland facies, and (3) rocks within the Ouachita structural belt. The latter include (a) rocks of Ouachita facies deformed but not metamorphosed, (b) rocks of Ouachita facies that are deformed and metamorphosed, and (c) rocks of foreland or transitional facies that are deformed and locally slightly metamorphosed. The boundary of the deformed belts transects the facies boundary, which indeed is a transitional boundary in space and has varied through Paleozoic time.

In some areas along the front of the Ouachita belt, rocks of foreland facies in the frontal basins are folded. In the McAlester basin where these folds have been mapped on the surface their axes are broadly parallel to structures in the Ouachita belt; in parts of the Fort Worth, Kerr, and Val Verde basins where Paleozoic structures are concealed by overlying Mesozoic rocks, cores show that foreland Paleozoic beds along the front dip steeply in some areas. Structures in the foreland basins were produced by the same forces that deformed the Ouachita belt and are products of the Ouachita orogeny; here, then, the problem is where to place the frontal boundary of the Ouachita structural belt.

The boundary can be placed easily where strongly deformed Ouachita facies rocks have overridden gently deformed foreland facies rocks along low-angle thrust faults, and there is a clear cut structural break between them. A condition of this sort commonly occurs where the Ouachita geosyncline impinged on a stable foreland element. In some areas without frontal overthrusts (e.g., the Ouachita Mountains in Arkansas), the orogenic front is marked by a rather abrupt change in structural grain or pattern. Within the structural belt there are steep narrow folds, locally overturned, and locally accompanied by high-angle reverse faults; in the frontal basins the folds are broader and more gentle. In still other concealed areas, however, the boundary might not be sharp and Ouachita structures might pass gradually into foreland structures; perhaps such a condition prevails where the belt is bordered by a deep frontal downwarp (such as the Val Verde basin) that in itself achieved incipient mobility. Possibly in west Texas (Pl. 2) there are segments of the Ouachita belt where the boundary against the foreland is transitional within a deformed zone.

The terms *flysch* and *molasse* have been defined in various ways and have both been applied to sequences of rocks which differ substantially in stratigraphic character. The utility of the terms has been debated (Eardley and White, 1947), but they continue to be used and a number of authors have applied them to late Paleozoic sedimentary sequences within and adjacent to the Ouachita belt (Van der Gracht, 1931a, p. 498; P. B. King, 1937, pp. 87–88, 135; Cline and Shelburne, 1959, pp. 177, 205–206).

Flysch-molasse

Broadly speaking, the term flysch has been applied to rhythmically bedded sandstone-shale sequences that are syn-orogenic in character, that is to say, that were deposited in deep tectonic basins between or in front of actively rising elements, and the term molasse has been applied to post-orogenic sediments derived from erosion of the uplifted deformed belt and deposited in shallow water in basins in front of or bordering the orogenic sequences. American geologists tend to rather rigid descriptive and genetic definitions of these sequences based on mineralogy, texture, sedimentary structures, fossils, and mode of origin; some definitions require that flysch sequences be composed of turbidites. There is general acceptance of the principle that flysch must be a deep-water deposit and molasse must be a shallow-water deposit. European geologists, on the other hand, influenced by the classic Alpine flysch and molasse sequences, tend to place more importance on tectonic setting or relation to tectonic elements in their definitions and are less restrictive in applying stratigraphic and mineralogic criteria.

Consideration of the formation of these sequences through time within a developing orogenic belt suggests that rigid definitions are not in order. Tectonic basins differ in rate of subsidence and amount of filling, symmetry, and nature of source areas. Some flysch basins probably filled up so that the younger part of the sequence was deposited in shallow water; other flysch basins probably never filled; in some the water was warm and in others it was cold, thus affecting the amount and nature of carbonate rocks in the sequence. Although molasse deposits are considered post-orogenic, the classic molasse basin of the Alps was involved in the later stages of Alpine orogeny and the beds have been folded and broken by thrust faults. They are post-orogenic in the sense that they post-date the main geosynclinal and early orogenic periods. In some areas the change from flysch to molasse sedimentation was abrupt, in other areas it was gradual; in some areas molasse lies on flysch, in other areas the two facies are tectonically juxtaposed or occur in separate basins.

If not too rigidly defined, the terms flysch and molasse are very useful in regional stratigraphic and structural studies. There seems to be no justification for using them outside of an orogenic setting.

Petrographic Nomenclature

Early in the project it became evident that there was need for a classification of argillaceous and arenaceous sedimentary rocks showing varied degrees of weak metamorphism, and that such a classification did not exist. Because many of the samples available for study are limited to well cuttings, the distinguishing criteria of classification had to be those determinable from thin-section study. Rock characteristics that can be observed in outcrops or hand samples cannot be used for classification when the sample is limited to finely chipped bit cuttings. Furthermore, any classification which carried connotations of genesis was to be avoided—the classification had to be descriptive.

The writer and August Goldstein, Jr., dealt with this problem in earlier studies (Flawn, 1953, 1956) and proposed a classification based on degree of reconstitution of the clay minerals, presence or absence of cleavage or parting, and grain size. The classification finally adopted is a revision of this earlier attempt; it is based on degree of reconstitution and/or recrystallization and the presence or absence of preferred mineral orientation or parting, slaty cleavage, or foliation (Table 1).

The weakness of the classification lies in the difficulty of distinguishing new reconstituted mica and chlorite from degraded, frayed, and fibrous second-cycle mica and chlorite; determination of degree of reconstitution is strongly subjective. However, with practice, the fresh new sprouts of sericite and chlorite can with fair certainty be separated from the faded, washed-out, degraded mica and chlorite. The writer and Goldstein, working independently with the same rocks and commonly on the same thin sections, used this classification successfully. Masson (1955) in a study of the same rocks employed the name semislate, apparently as an alternative name for clay-slate.

Susceptibility of rocks to metamorphic changes depends on their original structure, mineralogy, fabric, and grain size. Eskola (1932) noted that presence of finely divided carbon in a rock inhibits metamorphic reactions. Moreover, within a deforming prism of rocks, stresses and temperatures are not everywhere equal—variations in degree of metamorphism occur within a single fold. There should thus be variations in metamorphic grade in sequences of weakly metamorphosed rocks as a result of differences in susceptibility to metamorphism and structural position. A rock reflects the temperature and stress conditions of its environment, commonly preserving a record of changes therein, with over-all control of the final product exerted by its original composition. The classification shown in Table 1 distinguishes three grades of metamorphism below that commonly referred to as low-grade metamorphism, namely, incipient, very weak, and weak. Alternations between unmetamorphosed, incipiently metamorphosed, and very weakly metamorphosed rocks occur in samples from a single borehole where there is no evidence to indicate structural dislocations. Thus, no fine lines of separation can be drawn between slight changes of metamorphic grade, and no great tectonic significance is implied by such changes. But in a broad regional study, plotting of degrees of weak metamorphism on a map establishes definite trends because the areal scope cancels out minor variations. These trends are persistent and have structural significance (Pls. 1 and 2).

Bokman has called the sandstones of the Stanley "graywackes," defining a graywacke as "... any sandstone containing 20 percent or more argillaceous material" (Bokman, 1953, p. 162). He says further that "Arenites bearing 0–20 percent matrix material and having the poor rounding and sorting characteristic of the graywackes (as opposed to the excellent rounding and sorting of the orthoquartzites) are defined as subgraywackes." Although there is much support for this usage of graywacke (Pettijohn, 1949; Krumbein and Sloss, 1951;[5] and Tallman, 1949), the writer prefers to use the term graywacke for rocks with a particular mineralogical composition, following Krynine (1948) and Folk (1954, 1956) who define the rock on a mineralogical basis as a sedimentary rock containing grains of quartz, chert,

[5] More recently (Dapples, Krumbein, and Sloss, 1953) these authors have adopted another classification with more of a mineralogical basis.

TABLE 1. *Classification of metamorphosed argillaceous and arenaceous rocks.*

	DEGREE OF METAMORPHISM									
	None (Not reconstituted,[1] not recrystallized[2])		*Incipient* (Matrix<25% reconstituted, quartz and feldspar not recrystallized)	*Very weak* (Matrix>25%<50% reconstituted, quartz and feldspar not recrystallized)		*Weak* (Matrix>50%<100% reconstituted, quartz and feldspar not recrystallized)		*Low grade* (Matrix 100% reconstituted, quartz and feldspar may or may not be recrystallized)	*Medium to high grade* (100% reconstituted, completely recrystallized)	
ARGILLACEOUS ROCKS	without parting or preferred mineral orientation	mudstone claystone	metamudstone metaclaystone	without preferred mineral orientation or slaty cleavage	low-rank argillite	without slaty cleavage or foliation	high-rank argillite	low-rank hornfels	without foliation	high-rank hornfels
ARGILLACEOUS ROCKS	with parting or preferred mineral orientation	shale	metashale	with preferred mineral orientation or slaty cleavage	clay-slate	with slaty cleavage or foliation	slate	slate, phyllite, or schist[3]	with foliation	schist[3]
ARENACEOUS ROCKS	siltstone and sandstone			low-rank metasiltstone and low-rank metasandstone		high-rank metasiltstone and high-rank metasandstone		metaquartzite		

[1] Reconstitution = formation of new minerals by metamorphic processes, e.g., formation of micas and chlorite from clay minerals.
[2] Recrystallization = recrystallization of original detrital quartz and/or feldspar, not carbonate minerals.
[3] Slate is distinguished by the presence of slaty cleavage; schist and phyllite are separated on grain size—if mica or chlorite plates cannot be resolved by the unaided eye, the rock is a phyllite (the separation is commonly made within the grain size range (0.1 to 0.5 mm).
Conditions of metamorphism may be such as to produce medium or high-grade foliate rocks with a grain size of less than 0.5 mm. Some petrographers classify these rocks as phyllites (e.g., garnetiferous hornblende phyllite) because of the small grain size; other petrographers prefer to restrict the term phyllite to low-grade metamorphic rocks and term such high-grade rocks as very fine-grained schist.

metamorphic rock fragments, and mica in a clay-mica matrix. (Feldspar is not a definitive constituent.) Rocks defined as graywacke by Bokman are herein called argillaceous sandstone. The basic sandstone type of the Stanley under this scheme is angular, poorly sorted, argillaceous feldspathic sandstone, not graywacke. Fan and Shaw (1956) applied the term low-rank[6] graywacke to sandstones of the Tesnus formation. The mineral percentages given by Fan and Shaw (1956, Tables 1 and 2) show that rock fragments constitute only 1 to 3 percent of the sandstone while the clayey matrix ranges from 20 to 40 percent. According to the Krynine classification (1948, p. 137), a rock must contain at least 20 percent metamorphic rock fragments, micas, and clayey matrix to qualify as a graywacke. The inclusion of "clayey matrix" with metamorphic rock fragments and micas as one pole of the composition triangle (other poles are quartz-plus-chert and feldspar) was unfortunate because it permits classification as graywacke of sandstones containing a relatively high percentage of clay and little or no metamorphic rock fragments and mica. This was apparently not Krynine's intention because it subverts the mineralogical basis of his classification. Folk (1954) corrected this by establishing the following composition triangle—Q (quartz and chert), F (feldspar and all igneous rock fragments), and M (mica, metamorphic rock fragments, and metaquartzite)—and requiring that a rock contain 25 percent of mica, metamorphic rock fragments, and metaquartzite (stretched quartz mosaic) to qualify as a graywacke. Under the Folk scheme, which the writer favors, the Tesnus rocks described by Fan and Shaw are subgraywackes or argillaceous sandstones.

Williams, Turner, and Gilbert (1954) distinguished a large group of sandstones containing more than 10 percent clay as "wackes" and then, on the basis of mineralogy, separated a "lithic wacke," an "arkosic wacke," a "feldspathic wacke," etc. This recommendation also seems to weaken the utility of the term graywacke; it destroys its well-accepted mineralogical meaning but not to the extent that the Tallman-Pettijohn-Bokman definition does. The issue seems clear—graywacke is a term accepted by the great majority of geologists as a label for sandstones consisting of quartz, more or less feldspar, metamorphic rock fragments, chert, and mica in a dark clay-mica matrix. Why emasculate the term and apply it to rocks which can be perfectly described as argillaceous sandstones?

An interesting, up-to-date discussion of the entire subject of graywackes is given by Reed (1957).

Many of the sedimentary rocks studied during this project contain dark to opaque brown to black amorphous material with luster and color varying from brilliant black to dull black to resinous brown to dull brown. Such noncrystalline organic material has in the past been described by such general terms as asphaltum, bitumen, sapropel, and by a host of specific terms. Most definitions, however, prescribe a particular origin or chemical character for the material and do not lend themselves to simple microscopic description in thin section. In this report either the term bitumen (adjective, bituminous) is used as a general term for dark-colored noncrystalline organic compounds or these compounds are simply referred to as dark organic material; the term bitumen as used herein carries no connotations of any particular mode of genesis and may thus include organic material of both animal and plant derivation. In many of the rocks examined the bituminous material is mixed with more or less clay. Fragmental plant material in various stages of carbonization (including sooty carbon) is referred to as carbonaceous material; graphite and graphitic material are identified by the characteristic metallic luster.

[6] In the Krynine classification, low-rank and high-rank are indicators of the feldspar content of the graywacke; Folk (personal communication, 1957) suggested the use of graywacke alone to replace low-rank graywacke and feldspathic graywacke as a substitute for high-rank graywacke.

Recognition of Stanley, Jackfork, and Atoka Sandstones in Subsurface

It is not possible to make an unequivocal determination of Stanley, Jackfork, and Atoka lithology from examination of *one* thin section. Accidents of sedimentation can duplicate Stanley-type lithology in Jackfork or Atoka strata, but such duplication is the exception to the rule, and it is possible to make distinctions between the Stanley, Jackfork, and Atoka sandstones with confidence by examination of a suite of thin sections covering a sequence of the formation. The units are distinguished by study of the sandstones and not the intercalated shales.

Stanley sandstones are angular, poorly sorted, argillaceous feldspathic quartz sandstones commonly containing a high percentage of angular and modified garnet in the heavy mineral fraction. According to Bokman (1953, p. 166) this garnet is not present in the Stanley east of McCurtain County, Oklahoma; from the writer's observations, the garnet is present in Stanley sandstones as far south as Travis County, Texas. The feldspar in the Stanley sandstones is mostly sodic plagioclase. Percentages of quartz, feldspar, and clay matrix vary considerably; feldspar ranges from 5 to 20 percent of the rock, averaging about 10 percent; the clay matrix commonly ranges between 10 and 20 percent. The quartz is for the most part made up of strongly undulose and composite grains. Shale fragments, chert fragments, and slate-phyllite fragments are common in small amounts. Carbonate is rare except for cone-in-cone carbonate which occurs sporadically. Zircon and tourmaline rank next to garnet in the heavy mineral fraction.

In the Fort Worth basin area the Atoka sandstones are angular to subround, poorly to fairly well-sorted, commonly calcareous quartz sandstones. Feldspar content is low. Modified to round garnet is sporadically present. Some samples are argillaceous but in general there is less clay than in the Stanley. The distinction, then, is made on basis of greater degree of rounding, better sorting, low feldspar content, and presence of carbonate. Confirmation of Atokan age is given where Marble Falls limestone is penetrated beneath the sandstone and shale sequence.

Suites of thin sections from outcrop samples, examined by the writer, and Bokman's descriptions (1953) show that Jackfork sandstones are mostly subangular, mostly fairly well-sorted quartz sandstones containing little or no feldspar and very little clay matrix; garnet is rare. The Jackfork was penetrated by a number of wells in Fannin County but is unknown elsewhere in Texas.

THE SURFACE OF PALEOZOIC AND METAMORPHIC ROCKS

General remarks.—Prior to the deposition of Cretaceous rocks, a low-relief erosion surface was widely developed across Texas. This surface, the Wichita paleoplain (Hill, 1901, pp. 363–367), sloped gently southeast and truncated older rocks. In the area of the Ouachita structural belt, the erosion surface cut across deformed Paleozoic rocks and metamorphic rocks as far south and east as the shore of the Jurassic basin. Wells in north-central and north Texas have penetrated red soils developed on the erosion surface, but there are insufficient data to determine their areal extent and depth. In some wells the Paleozoic or metamorphic rocks are weathered to a depth of 50 or more feet. In sandstones, slates, phyllites, and metaquartzites, feldspar and mica are partly or completely altered to clay; hematite and limonite are abundant.

That part of the Wichita paleoplain developed on the interior part of the frontal zone and the interior zone of the Ouachita belt was warped and dislocated by later tilting and faulting accompanying development of the Gulf Coast basin and the fault systems along its northern margin.

Configuration of the pre-Cretaceous surface.—Configuration of the pre-Cretaceous surface in Texas and southeast Oklahoma is shown by 500-foot contours on Plate 4. This map is generalized from the well data, and sharp local dislocations due to faulting have been eliminated.

That part of the surface lying over the frontal zone of the belt and the immediately adjacent foreland is probably typical of the entire surface that existed before the downwarping and faulting which affected the southeasterly part during the Tertiary. It is a low rolling surface with a persistent southeast slope of about 50 feet per mile and hills rising several hundred feet above the general level. Probably there is more abrupt topography where the surface intersects Ouachita cherts, but well control is not adequate to map these areas in detail.

Eastward and southward the Wichita paleoplain is tilted gulfward and the dip increases to about 200 feet per mile; still farther toward the Gulf a line of flexure corresponding to the Luling-Mexia-Talco fault system tilts the surface more steeply and the dip increases to about 500 feet per mile (Pl. 4).

FOSSILS IN OUACHITA FACIES ROCKS

Fossils are not common in outcropping Ouachita rocks and examination of well cores and cuttings of Ouachita facies rocks also has revealed very few. Most of the scarce fossils found in the Ouachita Mountain area occur in Jackfork, Johns Valley, and Atoka beds; this includes the famous "Morrow fauna" of Honess (1924)[7] and fragmental invertebrate material composed of conodonts, spicules, bryozoans, gastropods, pelecypods, ostracodes, orbiculoids, radiolarians, goniatites, and plant remains (Harlton, 1934; Miser, 1934b; Bokman, 1953; Cline and Shelburne, 1959). Organic remains in the underlying Stanley are mainly restricted to radiolarians, conodonts (Hass, 1950, 1956), and more or less carbonized plant debris (David White, 1934). In the Marathon region the Dimple and Haymond formations contain a sparse fauna of fusulinids, other foraminifera, brachiopods, gastropods, pelmatozoans, spicules, and plant remains (P. B. King, 1937, pp. 64, 71–72). Fossils in the Tesnus are more scanty. P. B. King (1937, p. 61) reported plant remains, spicules, and foraminifera (in the upper part). Fan and shaw (1956) noted conodonts and radiolarians in the lower part. In extensive thin-section examinations during this project, carbonaceous plant fragments were observed throughout the Mississippian-Pennsylvanian beds, but few other organic remains were seen, other than phosphatic fragments of dubious origin, spores, and rare pelmatozoan plates. More careful sample preparation might produce a more useful assemblage of conodonts and spores.

Lower Paleozoic Ouachita rocks contain abundant organic material in the siliceous sequences both in outcrop and subsurface, but these fossils are limited to conodonts, radiolarians, spores, and spicules, and, in the shale-chert section, graptolites. In the Marathon area there is a rather abundant lower Paleozoic fauna composed largely of linguloid and obuloid brachiopods, graptolites, and trilobites; there is also a foreland facies coral-bryozoan-cephalopod fauna extending southward in fingers into the Marathon Basin area. Fossil wood is found in the Caballos. Studies of faunas from the outcrops in the Ouachita Mountains and Marathon Basin have been made by Cooper (1931, 1935), C. E. Decker (1936), Henbest (1936), P. B. King (1937, Aberdeen (1940), Ruedemann (1947), Haas (1951, 1956), Graves (1952), J. L. Wilson (1954b), Elias (1959), and Berry (1960). Thin sections of well cores and cuttings of cherts and siliceous shales show numerous radiolarian tests, spicules, and spores. Gastropods, commonly pyritized, and pelmatozoan debris occur sporadically in limestones of the Bigfork chert.

Graptolites have been reported in samples from five wells: Simpson-Fells Oil Company No. 1 G. W. Wall, Grayson County (Miser and Sellards, 1931, pp. 818–819) (p. 264); Olson Drilling Company No. 1 Southwestern Life Insurance Company, Grayson County (this report, p. 260); General Crude Oil Company No. 1 Earnest Day, Coryell County (this report, p. 246); Nolan Bell Oil Company No. 2 William Bacon, Bell County (Sellards, 1931b, p. 827) (p. 219); and Milham Oil Corporation No. 1 Bassett, Terrell County (Lewis, 1941, pp. 78–79) (p. 307). Trilobites and fusulinids occur in Gulf Oil Corporation No. 1 D. S. C. Coombs, Brewster County (p. 234). A gastropod was found in Richardson Oil Company No. 1 Martin Rose in Kinney County (p. 286).

[7] Originally thought to be in the Jackfork, now known to be in Johns Valley and Atoka beds (Cline and Shelburne, 1959, p. 203).

The Ouachita Mountains of Oklahoma and Arkansas

AUGUST GOLDSTEIN, JR.

General Statement

The Ouachita Mountains lie between the McAlester basin on the north and the Gulf Coastal Plain province on the south and extend westward from Little Rock, Arkansas, to Atoka, Oklahoma (fig. 1). The total area is about 12,000 square miles, of which slightly more than half is in Arkansas.

Topographically, the Ouachita Mountain region consists of numerous ridges trending nearly east-west, several intermontane basins, and a dissected piedmont plateau (Athens plateau) along the southern border of the Ouachita Mountains in Arkansas. The climate of the region is mild and rainfall is abundant. The soil is generally poor for agricultural purposes, and most of the region is heavily covered by yellow or shortleaf pine and several varieties of oak. Nevertheless, the more competent strata are generally well exposed, but most of the incompetent beds are poorly exposed.

The geology of the area has been described by numerous investigators. Among the major modern studies are those of Miser (1917, 1921, 1929, 1934b, 1943, 1959), Miser and Honess (1927), Miser and Purdue (1929), Purdue and Miser (1923), Honess (1921a, 1923), Ulrich (1927), Van der Gracht (1931a), David White (1934, 1937), Harlton (1934, 1938, 1953), Hendricks (1943, 1959), Hendricks et al. (1937, 1947), Hass (1950, 1951), Bokman (1953), Goldstein and Hendricks (1953), Pitt (1955), Cline (1956b, 1960), Cline and Moretti (1956), Cline and Shelburne (1959), Misch and Oles (1957), Reinemund and Danilchik (1957), and Shelburne (1960).

The aggregate thickness of the sedimentary rocks in the DeQueen and Caddo Gap quadrangles of the Ouachita Mountains in Arkansas ranges from a minimum of 21,720 feet to a maximum of 26,875 feet (Miser and Purdue, 1929, p. 22). The Cambrian (?) and Ordovician strata range from a maximum of about 3,300 feet thick in southeastern Oklahoma to as much as 4,300 feet in western Arkansas. The Silurian and Devonian strata range from 1,440 feet thick in southeastern Oklahoma to as much as 2,750 feet in western Arkansas. Mississippian and Pennsylvanian strata may have a maximum thickness of between 18,000 and 22,000 feet, but the complexity of their folding makes it difficult to measure complete sections, and their true thickness is uncertain. Furthermore, recent deep drilling in and near the Ouachita Mountains strongly suggests that the aggregate outcrop thicknesses of the lower Paleozoic section may be a minimum, and that much greater thicknesses of lower Paleozoic sediments are concealed beneath younger beds. Table 2 is a generalized stratigraphic section of the Paleozoic sequence exposed in the Ouachita Mountains.

Most of the brief descriptions of gross lithology and thicknesses herein are based on published articles, particularly those of Miser and Purdue (1929), Honess (1923), and Hendricks et al. (1937, 1947). The petrographic descriptions are based on original work.

TABLE 2. *Paleozoic formations of the Ouachita Mountains.*

AGE	FORMATION	THICKNESS (feet)	LITHOLOGY
	Major unconformity		
Pennsylvanian	Atoka	1,500–19,000	Shale, light gray, silty, micaceous, and flaky with interbedded fine- to coarse-grained, micaceous sandstone with very abundant sole markings. Thin siliceous shales near base and in lower part of formation.
Mississippian and Pennsylvanian	Johns Valley	200–1,000	Shale, light gray to tan, dark gray near base, and thin beds of sandstone and limestone. Large erratic masses of limestone or shale of foreland facies are found near the base of the formation, and exotic boulders, pebbles, and granules occur at numerous horizons. Formation equivalent in part to Caney, Sycamore(?), Springer, Wapanucka, and Chickachoc of frontal belt.
Mississippian	Jackfork	1,150–7,000	Sandstone, medium to coarse grained, hard, with intercalated shale. Sole markings are abundant in the sandstones. Four beds of siliceous shale and one bed of maroon to green shale are identifiable over long distances and form marker beds.
	Stanley Hatton tuff lentil	6,000–12,000 (0–90)	Shale, dark colored, mostly gray, interbedded with dark gray argillaceous siltstone and very poorly sorted fine- to very fine-grained argillaceous chloritic sandstone. Beds of siliceous shale identifiable over long distances are found at several horizons. Cone-in-cone concretions are abundant at places. Several beds of acidic vitric tuff are found near the base of the formation.
	Hot Springs sandstone	0–200	Sandstone, hard, quartzose, fine to very fine grained. Small amounts of interbedded shale and locally conglomeratic near base. Crops out only in relatively small area near Hot Springs, Arkansas.
	unconformity		
Devonian and Mississippian	Arkansas novaculite	230–950	Upper member—green, brown, and gray radiolarian chert and radiolarian shale. Upper middle member—red and green radiolarian shale, siliceous shale, radiolarian chert, and bituminous chert. Lower middle member—light gray to black bituminous spore-bearing chert and black papery bituminous shale. Lower member—white to green massive spiculitic chert and green laminated siliceous shale. (In Broken Bow—Benton uplift the upper and upper middle members are combined into a single member of white, calcareous, manganiferous chert.) Woodford and Pinetop cherts of frontal belt are equivalent in part to Arkansas novaculite.

	unconformity		
Silurian	Missouri Mountain	0–300	Shale, hard, green, siliceous, sandy in part. Thin beds of finely laminated chert and quartzose sandstone and local lenses of sandy chert conglomerate.
	unconformity		
	Blaylock	0–1,500	Sandstone, gray to green, thin bedded, fine grained, with interbedded shaly micaceous siltstone and dark fissile shales. Veins of quartz and smoky quartz are abundant. Formation is present only in part of Broken Bow—Benton uplift.
	unconformity		
Ordovician	Polk Creek	0–175	Shale, soft, brown, platy in most of formation; hard, black, bituminous, and siliceous near base. Abundant graptolites. Thin streaks of quartzitic sandstone and oolitic limestone in Arkansas.
	Bigfork	600–800	Upper unit—black, noncalcareous, bituminous chert and black bituminous papery shale. Lower unit—gray to brown calcareous chert, siliceous limestone, clastic limestone, and cherty shale.
	Womble	240–1,000	Shale, black to green, with thin interbeds of quartzose sandstone and limestone. Mostly schistose, micaceous, chloritic, fine-grained sandstone in McCurtain County, Oklahoma. Some siliceous bituminous shale near contact with Bigfork chert.
	Blakely	0–500	Shale, black to green, interbedded with fine- to medium-grained quartzose sandstone. Some veins of smoky quartz.
	Mazarn	1,000±	Shale, black to green, banded, clayey, fissile, with thin layers of gray sandstone and bluish-black limestone. Veins of quartz and calcite.
Cambrian (?) or Lower Ordovician	Crystal Mountain	5–100±	Sandstone, massive, light gray, calcareous to quartzitic. Many quartz veins and crystals. Chert conglomerate at base of formation in McCurtain County.
	unconformity		
	Collier	180±	Shale, black, graphitic, and dark-colored siliceous limestone. Some dense black chert in Arkansas.
	Lukfata	145+	Upper member—massive quartzose, fine- to medium-grained sandstone with shale laminae. Middle member—interbedded platy sandstone and shale. Lower member—thin-bedded limestone and shale. Base of formation is not exposed.

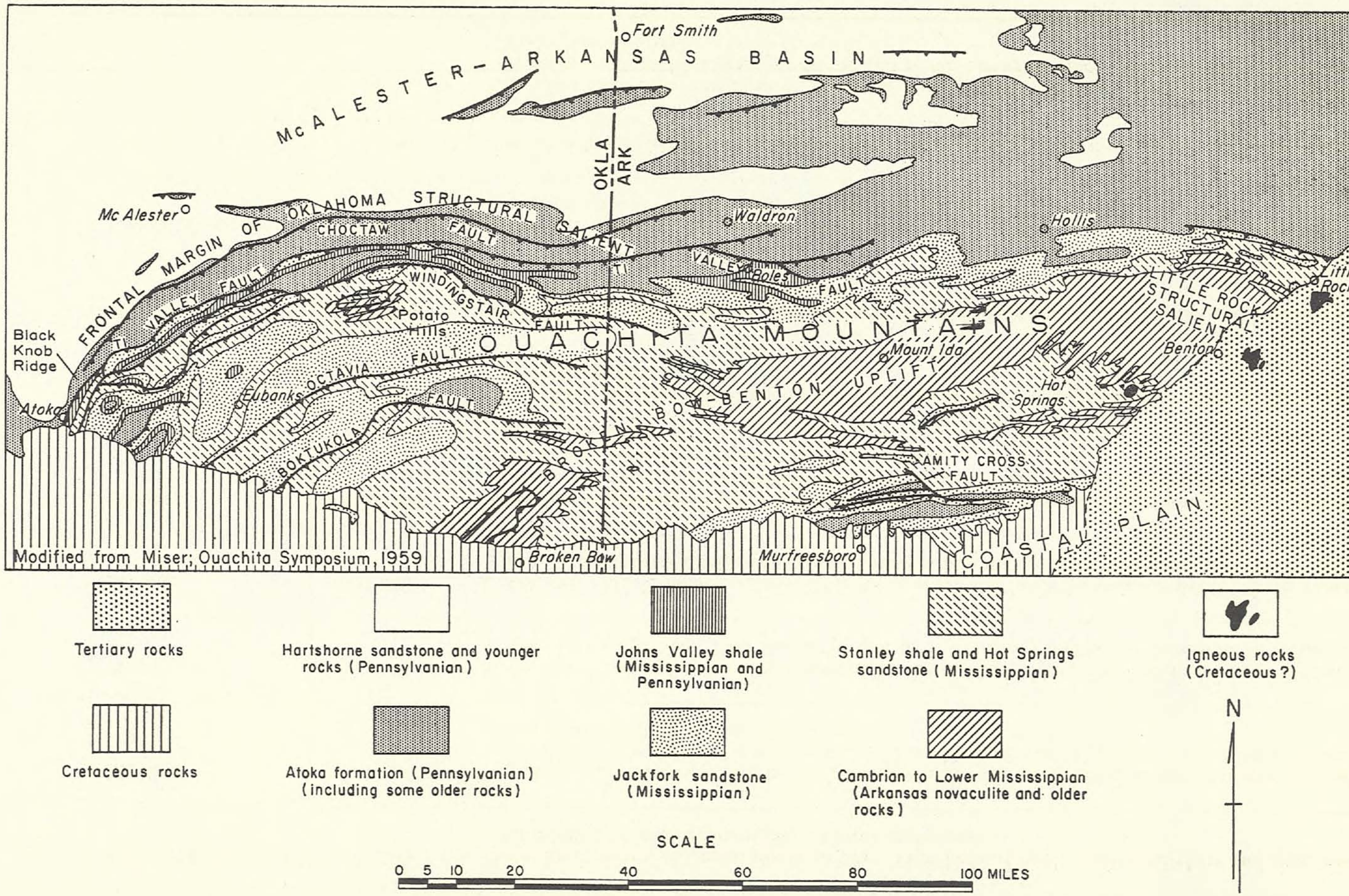

Fig. 1. Ouachita Mountains in Oklahoma and Arkansas.

Stratigraphic Synopses

Lukfata sandstone.—The Lukfata sandstone formation was named by Pitt (1955) for exposures in McCurtain County, Oklahoma. However, the strata which comprise the formation were described originally as part of the Crystal Mountain sandstone and were so mapped by Honess (1923). In order to clarify these stratigraphic relationships, some digression and discussion of these matters are appropriate at this point.

For many years it was believed that the oldest rocks exposed in the Ouachita Mountains in both Oklahoma and Arkansas were the shale and limestone of the Collier formation. The age of the Collier was usually reported as Cambrian or Cambrian(?). The Crystal Mountain sandstone, which overlies the Collier and is locally conglomeratic at its base, was considered to be Cambro-Ordovician or Ordovician(?). No usable fossils have been reported from either the Collier shale or the Crystal Mountain sandstone. The Mazarn shale, which overlies the Crystal Mountain with apparent conformity, contains Lower Ordovician graptolites.

Pitt (1955, 1959), mapping the core area of McCurtain County, divided the Crystal Mountain sandstone into two formations, one of which underlies the Collier shale and one of which overlies it. The older formation was named the Lukfata sandstone, and the name Crystal Mountain sandstone was retained in a restricted sense for the younger formation. The Lukfata formation contains the oldest known rocks in the Oklahoma portion of the Ouachita Mountains; the Collier strata are still the oldest known rocks from the Arkansas Ouachita Mountains. Both Branson (1956) and Ham (1959) considered the entire sequence of Lukfata-Collier-Crystal Mountain to be of Lower Ordovician age and equivalent to the middle part of the Arbuckle group. However, the quartzose sandstones of the Lukfata and Crystal Mountain at the time of deposition were probably quite similar to those of the upper Reagan of the Arbuckle Mountains and the Dagger Flat of the Marathon uplift, both of which are fossiliferous and are of Upper Cambrian age. Consequently, the writer favors retaining an age assignment of Cambro-Ordovician or Ordovician(?) until there is some positive evidence to the contrary.

In McCurtain County, Pitt (1955, pp. 13–14) divided the Lukfata sandstone formation into three members: a lower member of interlaminated shale and thin-bedded limestone; a middle member of interbedded platy sandstone and shale; and an upper member of more massively bedded sandstone with some thin interbeds of shale. The exposed thickness of the formation is 145 feet and its base is nowhere exposed. Petrographically the Lukfata sandstone (metasandstone) is a quartzose sandstone which has undergone weak to low-grade metamorphism. The individual sandstone beds are mostly fine to medium grained and well sorted. Most of the quartz grains were originally rounded to subrounded, but their outlines were modified by secondary enlargement and subsequent reaction with the matrix during metamorphism. Aggregates of silt and sand-size secondary quartz crystals, dolomite rhombs, detrital grains of shale, and silty shale are also present. Virtually all of the original interstitial clay has been reconstituted into new sericite and chlorite.

Collier shale.—The Collier shale (clay-slate) is the oldest exposed unit in Arkansas, consisting there and in McCurtain County, Oklahoma, of contorted, graphitic black shale and clay-slate interbedded with thin-bedded, dark-colored bituminous limestones. The shales are blue black, hard and slaty to soft, and cut by thin stringers and veins of milky quartz and calcite. The limestones are compact, finely crystalline, dark bluish gray, thinly bedded, crumpled, and contorted. The Collier is at least 180 feet thick in the core area of McCurtain County; it may be as much as 500 feet thick in Arkansas. Much of the Collier shale in Arkansas is sericitic and has slaty cleavage at an angle to the bedding planes.

Thin sections of the Collier limestones show laminated, argillaceous, contorted, finely crystalline limestone with laminae and streaks of black, graphitic, pyritic shale. Detrital silt and sand grains are scattered through some samples; replacement of calcite by silica is widespread in some beds. Microstylolites and veinlets of quartz and calcite are present.

Crystal Mountain sandstone.—The Crystal Mountain sandstone (metasandstone), whose type locality is in the Crystal Mountains of Arkansas, is about 850 feet thick in this area and is composed almost entirely of sandstone. The sandstone is massive, coarse grained, and quartzose. Silica cement is dominant, but some beds are cemented by calcite. A network of veins of white quartz from a fraction of an inch to several inches thick cuts through the sandstones, and clusters of quartz crystals line the walls of fissures at many places. Small amounts of black to greenish clay shale are interbedded with the sandstone, and a thin basal conglomerate of limestone pebbles, chert fragments, and quartz sand ranging up to granule size is widespread.

In the core area of McCurtain County, Oklahoma, the Crystal Mountain sandstone (as restricted by Pitt) is as much as 100 feet thick. It consists of quartzose, well-sorted, very fine- to medium-grained sandstone (metasandstone) cut by veinlets of quartz. The rocks have undergone weak to low-grade metamorphism. Contacts between adjacent sand grains are complexly sutured and interlocked; the individual quartz grains have been granulated and elongated, and the original interstitial clay has been reconstituted into new sericite and chlorite.

Mazarn shale.—The Mazarn shale (clay-slate) of Early Ordovician age conformably overlies the Crystal Mountain sandstone. The Mazarn formation contains an abundant graptolite fauna of the Deepkill zone, probably of early Beekmantown age; it is the oldest fossiliferous formation in the Ouachita Mountains. The Mazarn is predominantly green to black, banded, clayey, fissile shale and clay-slate with small quantities of bluish-black thin-bedded, compact, finely crystalline limestone and gray, fine-grained, laminated, quartzitic sandstone. In Arkansas, where the Mazarn is about 1,000 feet thick, most of the shales are jointed and slaty cleavage, at an angle to the bedding, is widely developed. In some places the differently colored layers produce ribboned slate. Veins of white quartz and calcite cut the rocks in all directions. Most thin sections of the Mazarn are dark-colored, possibly graphitic, laminated, silty, siliceous and/or calcareous clay-slate and indurated shale, whose laminae are highly contorted and irregularly plicated. Some of the argillaceous material in the lighter-colored layers has been reconstituted to chlorite, and pyrite is abundant in many of the darker layers.

Blakely sandstone.—The Blakely sandstone (metasandstone) of Middle Ordovician age conformably overlies the Mazarn shale and varies in thickness from 0 to 500 feet in the central Ouachita Mountains. The Blakely contains Deepkill graptolites that are apparently of a slightly younger zone than those in the Mazarn. The Blakely is largely interbedded shale and sandstone, with the shale making up about 75 percent of the whole. The shale (clay-slate) is mostly black but contains green bands like those in the Mazarn shale. Sandstones (metasandstones) of the Blakely occur in beds generally less than 10 feet thick and are quartzose, moderately ferruginous and argillaceous, and fine to medium grained. Many of the larger quartz grains appear originally to have been rounded to subrounded, but they are now mostly subangular, due partly to mechanical granulation and partly to reaction with the clay matrix during metamorphism. The clay matrix has been altered to intercrystallized sericite, chlorite, and microcrystalline quartz. Some specimens are cut by quartz veinlets, and some contain iron-stained rhombic cavities.

Womble shale.—The Womble shale of Early(?) and Middle Ordovician age conformably overlies the Blakely sandstone. All but one collection of graptolites from the Womble are of Normanskill type, and the entire formation may be of Middle Ordovician age. The formation is from 250 to 1,000 feet thick on the outcrop, but well data suggest that it is quite thick in some areas, possibly as much as several thousands of feet. In western Arkansas and near Black Knob Ridge, Oklahoma, the Womble is largely black clay shale with some thin green layers and with thin interbeds of sandstone and limestone. Slaty cleavage is well developed at many places in Arkansas. Coarse, well-rounded, frosted quartz sand grains are fairly common in some shales. In McCurtain County, Oklahoma, the Womble is mostly soft, micaceous, argillaceous sandstone (metasandstone) and was called the "Womble schistose sandstone" by Honess (1923, p. 62).

Cuttings from wells drilled in southeastern Oklahoma and Grayson County, Texas, strongly suggest that the Womble shale contains two distinct units. The upper unit is several hundred feet thick and is made up of massive to irregularly bedded, bituminous, siliceous, dark gray to black shale with a brown streak. This upper unit passes gradationally upward into the Bigfork chert and is transitional downward into the lower unit of the Womble. The lower unit is several thousand feet thick and consists largely of alternating thin beds of gray and green shale with thin interbeds of very fine-grained sandstone, siltstone, and limestone. The shale is fissile, platy to splintery, and contains abundant graptolite fragments along bedding planes. Near Black Knob Ridge the light-colored argillaceous rocks vary from unaltered shale without reconstitution of the "clay" matrix to clay-slate with abundant reconstituted sericite and chlorite. Radiolarians and ostracode carapaces are visible in some slides. The darker-colored shales are commonly harder and more brittle and contain abundant disseminated silica, red-brown bituminous material, pyrite, spores, and radiolarians. Many of these more competent siliceous shales are fractured and veined.

The argillaceous sandstone (metasandstone) of the Womble in McCurtain County is fine to medium grained, chloritic, and sericitic. These rocks show definite weak to low-grade metamorphism. The quartz grains have been stretched and granulated in part, and the original clay-silt ("mud") matrix has been completely reconstituted into aggregates of chlorite, sericite, biotite, and quartz. The borders of the detrital sand grains have a characteristic corroded appearance due to reaction with the clay of the matrix during metamorphism.

Bigfork chert.—The Bigfork chert of Middle Ordovician (Trenton) age conformably overlies the Womble shale. The fauna consists of graptolites, small brachiopods, ostracodes, trilobites, conodonts, spicules, spores, and radiolarians (Pl. 5, A); most of the graptolites are conspecific with those found in the Viola limestone of the Arbuckle region (Hendricks et al., 1947). The Bigfork formation is about 600 feet thick at Black Knob Ridge, about 800 feet thick in McCurtain County, and about 700 feet thick in western Arkansas.

In the DeQueen and Caddo Gap quadrangles (Miser and Purdue, 1929), the Bigfork consists of chert interbedded with some shale and minor amounts of limestone. The chert is black, compact, brittle, and mostly thin bedded. The shale is black, siliceous, carbonaceous, and papery. The limestones are black, siliceous, and occur in thin lenses and layers.

At Black Knob Ridge the Bigfork is divided into a thick lower unit of gray to brown calcareous chert, siliceous limestone, and cherty shale, and a thinner upper unit, making up about one-fourth to one-third of the formation, which consists of alternating black paper shale and black noncalcareous chert.

The limestones in the lower unit at Black Knob Ridge are medium crystalline to sublithographic and generally pyritic and argillaceous; the silica in the siliceous limestones is mostly cryptocrystalline quartz, but there is some chalcedony. Sponge spicules, ostracode carapaces, and graptolite fragments are abundant; crinoid columnals and fragmentary calcareous fossils of other types are less common.

The bedded cherty shales of the lower unit of the Bigfork near Black Knob Ridge are irregularly laminated, color banded, pyritiferous, and bituminous. Many of the siliceous rocks contain relict euhedral carbonate rhombs. Most specimens are fractured and contain fissure-fillings of quartz and/or calcite. Spores, poorly preserved radiolarians, and sponge spicules are the characteristic fossils in the cherty shales.

The chert and shale of the upper unit of the Bigfork in this area contain no calcareous fossils and very little calcite or dolomite. The chert is dark red brown to black, laminated, color banded, pyritiferous, and bituminous. It grades into the black shales by decrease of silica and an increase in clay and sapropelic material. Spores, radiolarians, sponge spicules, and abundant graptolite debris are characteristic.

Polk Creek shale.—Conformably overlying the Bigfork chert is the Polk Creek shale of Late Ordovician age. In Arkansas the Polk Creek is mostly black, fissile, carbonaceous shale containing a few thin, widely separated layers of chert and sandstone. It contains an abundant and well-preserved graptolite fauna. The thickness of the Polk Creek ranges from 0 to 175 feet, but the top of the formation is everywhere eroded at known outcrops in and near Black Knob Ridge, and its original thickness at the time of deposition is not known. In the Black Knob Ridge area, the Polk Creek shale near the Bigfork contact is hard, black, fissile, bituminous, and siliceous. This grades upwards into a soft, brown, platy shale with numerous small cavities containing soft, yellow, clayey pellets. Thin layers of black bituminous chert are interbedded in places, and thin streaks of quartzitic sandstone and oolitic limestone have been reported from Arkansas (Miser and Purdue, 1929). The Polk Creek shale is crumpled and slickensided in places and contains quartz veinlets and pyrite.

Thin sections of the siliceous shales show that they are thinly laminated and highly bituminous. Individual laminae range from nearly pure clay shale to nearly pure chert. Streaks of bituminous material are irregular and discontinuous. Most of these shales contain pyrite and are cut by veinlets of quartz and asphalt(?). Graptolites and spores are present.

In McCurtain County, Oklahoma, and in most of western Arkansas, some beds of the Polk Creek shale have been metamorphosed into clay-slate. This slate contains reconstituted sericite and chlorite, and part of it is moderately silty. Thin sections show abundant opaque inclusions.

Blaylock sandstone.—The Blaylock sandstone of Silurian age has a smaller areal extent than most of the other formations of the Ouachita Mountains. The Blaylock is only sparsely fossiliferous but contains some specimens of the *Monograptus* fauna, which is Silurian. The formation is missing in the northern and northwestern parts of the Ouachita Mountains, but it may be as much as 1,500 feet thick in the Caddo Gap quadrangle in Arkansas. The Blaylock is apparently conformable with and transitional to the underlying Polk Creek shale in McCurtain County, Oklahoma (Honess, 1923, p. 102), but in the DeQueen quadrangle Miser and Purdue (1929, p. 44) found a conglomerate locally at the base, suggesting a stratigraphic break. The Blaylock is absent at Black Knob Ridge.

In the DeQueen and Caddo Gap quadrangles of western Arkansas (Miser and Purdue, 1929, pp. 42–45), the Blaylock consists of sandstone and shale. The sandstone is somewhat more abundant, occurring in evenly bedded layers mostly 1 to 6 inches thick but attaining a thickness of 3 feet at places. Most of the sandstone is hard, compact, light to dark gray, laminated, and quartzitic, but some is soft and yellow. The shale is dark colored, micaceous, and fissile. Mostly it is dark gray to black, but some of it is buff.

In McCurtain County, the Blaylock is thin-bedded, fine-grained, greenish-gray, quartzitic sandstone with interbedded shaly sandstone and dark shales, all of which weather red. The lower part of the Blaylock is mostly shale, the bulk of the central part is fine-grained sandstone, and the upper part is about 40 percent shale and 60 percent sandstone (Honess, 1923, p. 94).

The Blaylock consists of coarse-grained siltstone (metasiltstone) and very fine- to fine-grained quartzose sandstone (metasandstone) that have undergone distinct weak to low-grade metamorphism. Most sandstones are fairly well sorted to well sorted, moderately micaceous, and slightly feldspathic. Abundant silt-size stable minor accessory ("heavy") minerals are present, including leucoxene, zircon, rutile, tourmaline, and staurolite. Almost every thin section contains quartz veinlets; some are simple fissure fillings, whereas other veinlets are compound, sinuous, bifurcating, and pinch and swell within very short distances.

In those sandstones which contained originally some interstitial "clay," the detrital grains have corroded edges due to reaction with the matrix. Most of the "clay" matrix has been reconstituted into anhedral green chlorite with some sericite. The abundant chlorite acts as a cementing material in many specimens; where original "clay" was lacking the cement is siliceous and the quartz grains are interlocked into the texture of a quartzite.

Missouri Mountain shale.—The bottom beds of the Missouri Mountain formation (Silurian) are transitional into the underlying Blaylock sandstone in McCurtain County, and for this reason Honess (1923, p. 109) considered the formations to be conformable. Miser and Purdue (1929, p. 44) were unable to determine definitely the nature of the Blaylock—Missouri Mountain contact in western Arkansas but suggested that there might be a stratigraphic break at this level. In the Black Knob Ridge area, the Blaylock is wedged out and the Missouri Mountain rests unconformably upon either the Polk Creek shale or Bigfork chert. The fauna of the Missouri Mountain consists largely of undescribed spicules, radiolarians, spores, and fragments of nondiagnostic chitinous or phosphatic megafossils; the Missouri Mountain is presumed to be Silurian because of its stratigraphic position.

In much of western Arkansas, the Missouri Mountain is a clay-slate with a conglomerate at the base and a few thin layers of sandstone and quartzite. The slate is red to green, is commonly dissected by joints in two or more sets, and has well-developed cleavage, which is parallel to the bedding at many places and oblique elsewhere. The sandstone and quartzite are in layers from 3 to 5 inches thick and occur mostly near the base and top of the formation.

In most of Oklahoma, the Missouri Mountain shale is from 0 to 300 feet thick and consists largely of red and green clay shale, siliceous shale, chert, and slate. Thin layers of sandstone and conglomerate are locally present, at various horizons.

Petrographically, the "shales" are mostly light-colored, chloritic clay-slate, silty and siliceous in part. The cherts are radiolarian and spiculitic, banded at places, micaceous, silty, and crowded with opaque inclusions. The sandstones are nearly unmetamorphosed in the Black Knob Ridge area, where they are fairly well sorted to well sorted, very fine grained to fine grained, and quartzose. Well-developed secondary enlargement of the quartz grains is typical, and most sandstones are cemented by silica. A typical conglomerate in the Missouri Mountain is a sandy and calcareous, granule chert conglomerate with a wide variety of detrital fragments including clear chert, dark brown bituminous chert, spiculitic chert, radiolarian chert, siliceous shale, limestone, dolomite, and chalcedony.

Stratigraphic Analysis

Pettijohn (1957) has summarized the abundant literature on the theory of the geosynclinal cycle and the relationship of sediment types to tectonics. He pointed out that in most geosynclinal basins there is a normal geosynclinal cycle in which the geosyncline is first initiated, then filled, and lastly (but not always) deformed and uplifted. The sediments which accumulate during the various stages of geosynclinal history are more or less petrographically distinct. In the early stages of a geosyncline the first sediments are usually orthoquartzites (quartzose sandstones) and carbonate rocks, followed by an euxinic facies of black shales with some siltstone, siliceous limestone, or chert. This facies is succeeded by the "flysch" facies in which large amounts of clastics are poured into a rapidly subsiding geosynclinal trough; the typical deposits of this facies are graywacke and dark shales. As the geosynclinal trough fills up, the "flysch" facies is succeeded by the "molasse" facies in which the sandstones (subgraywacke and protoquartzite) are coarser, cleaner, and cross-bedded. Finally, the geosyncline may be deformed and uplifted, with reducing conditions replaced by an oxidizing environment in which red mudstones and red sands become abundant.

Many recent writers have questioned whether the early Paleozoic sediments of the Ouachita Mountains region merit the title of geosynclinal facies, generally pointing out that the greater thicknesses of early Paleozoic sediments apparently occur in basins lying on the foreland side of the Ouachita structural belt and are of foreland facies. The writer has discussed this subject at some length previously (Goldstein, 1959a) and concluded that theoretical considerations based upon sandstone types, position of major unconformities, concealed thicknesses of sediments much greater than those measured at the outcrop, and faunal studies strongly suggest that there was a relatively complete geosynclinal cycle in the early Paleozoic in the Ouachita Mountains. However, the rocks exposed today in the Ouachita Mountains are not the axial sediments of this early Paleozoic geosyncline but were laid down distal to the axis, near the foreland edge of the downwarp; the true axial sediments of this geosynclinal cycle are probably south (Gulfward) of the Ouachita Mountains and are buried beneath younger rocks. Succeeding paragraphs will attempt to show the broad relationships of the early Paleozoic sediments in the Ouachita Mountains and how they fit into the concept of the geosynclinal cycle.

No rocks of Precambrian age crop out anywhere in the Ouachita Mountains, but rock and mineral grains incorporated in early Paleozoic sediments suggest that the original source for sediments of Ouachita facies was an area of acid igneous rocks. Miser (1921, 1934b, 1934c) originally inferred an area ("Llanoria") of Precambrian crystalline rocks south and east of the Ouachita structural belt which acted as a source of supply for sediments of Ouachita facies. Later modifications of the basic concept of Llanoria, notably by Van der Gracht (1931a) and P. B. King (1950) have emphasized that Llanoria probably was not a rigid, persistent, Precambrian highland which acted as a source area throughout the Paleozoic, but that most of the middle and late Paleozoic clastic detritus was derived from uplift, erosion, and re-deposition ("cannibalization") of previously deposited sediments of the geosyncline.

The oldest sedimentary rocks in the Ouachita Mountains are the quartzose sandstone (metasandstone) of the Lukfata in Oklahoma and the black carbonaceous shales and thin-bedded, dark limestone and siliceous limestone of the Collier formation in western Arkansas. At the beginning of Cambro-Ordovician or Ordovician(?) time, Llanoria was probably an area of low relief. The Lukfata and Crystal Mountain sandstones may represent the littoral facies of seas transgressing the area and reworking the exposed surficial deposits. The seas were muddy throughout most of Collier deposition, although they cleared at irregular intervals to allow deposition of some relatively pure limestones. Little coarse detritus was being supplied to the "starved depositional basin" of Collier time, and the water in which the Collier shale was deposited was moderately deep.

At the end of Crystal Mountain time the sea became muddy again and remained so throughout most of Early Ordovician time. The Mazarn formation of early Beekmantown age consists of black to green, carbonaceous graptolitic shales with thin sandstone and limestone, and, like the Collier, is also a "starved basin" shale deposited largely in an euxinic environment. Localized uplift towards the end of Mazarn time is marked by local conglomerates near the base of the Blakely formation in Arkansas. In this area, the Blakely formation consists of well-sorted quartzose sandstones and interbedded shales and limestones. It is succeeded by the black, carbonaceous and bituminous, graptolitic shales characteristic of the Womble in Arkansas. In McCurtain County, Oklahoma, the Womble is largely fine- to medium-grained, schistose, micaceous sandstone; Honess (1923, p. 64) was unable to calculate its thickness. These sandstones may be a relatively thin tongue or wedge of a larger sand deposit, possibly thickening rapidly southward, and laid down distal to the axis of an actively downwarping geosyncline.

Widespread volcanism in the Ordovician period has been noted by C. S. Ross (1928), who stated that thousands of square miles in the southeastern United States were covered with ash at this time. Ash falls similar to these are considered to be the primary source of silica for the chert in the Bigfork formation (Goldstein and Hendricks, 1953; Goldstein, 1959b). The clastic limestones in the lower unit of the Bigfork near Black Knob Ridge contain only a small amount of silica derived from these ash falls, which were limited in extent and sporadic in early Bigfork time, for these limestones have a calcareous fauna and were deposited in generally shallow and comparatively clear water. Replacement-type epigenetic chert is most common in these limestones, probably in part a result of surface exposure.

On the other hand, the dark-colored, bedded cherty shales in the lower Bigfork near Black Knob Ridge were highly siliceous originally and were deposited in periods of abundant supply of volcanic ash. They contain only radiolarians, spores, graptolites, and sponge spicules and were probably laid down in a high-silica euxinic environment unfavorable to the development of a calcareous benthonic fauna. These beds contain much primary silica derived from ash falls, although the ash was probably changed by submarine weathering into nearly pure silica before lithification of these deposits.

There is no sharp contact between the upper and lower units of the Bigfork in the western part of the Ouachita Mountains in Oklahoma, and one thickens as the other thins. By late Bigfork time the seas were consistently muddy and stagnant, and an euxinic black shale environment obtained. Volcanic ash falls were more persistent and widespread, and submarine weathering of this material supplied large amounts of silica to the black cherts and siliceous shales of the upper unit of the Bigfork. Goldstein and Hendricks (1953, p. 437) estimated that not over 10 to 20 percent of carbonate was ever present in the upper Bigfork, and even this original carbonate has been replaced by silica in the outcrop occurrences. In western Arkansas the Bigfork is almost entirely black chert with only minor amounts of limestone and thin interbeds of black bituminous shale.

Gradually the volcanic activity lessened, the supply of silica decreased, and the sediments of the upper Bigfork passed gradationally into the black, graphitic and bituminous, graptolitic shale of the lower part of the Late Ordovician Polk Creek formation, a typical deposit of an euxinic environment.

Near the axis of the early Paleozoic geosyncline, south of the present Ouachita Mountains, an orogeny may have begun near the end of Ordovician time, possibly extending well into the Silurian. As a result of this orogeny farther south, there were one or more epeirogenies in the Ouachita Mountains which may have stripped off large amounts of sediments and which did result in numerous stratigraphic breaks and minor unconformities. In the Black Knob Ridge area the Polk Creek shale is always eroded at the top and may be missing entirely. Over much of the central anticlinorium of the Ouachita Mountains, the Polk Creek shale is unconformably overlain by the Blaylock sandstone; in the rest of the mountain system the Polk Creek is unconformably overlain by the Missouri Mountain shale. The Blaylock sandstone has a very limited areal extent, being confined to only a portion of the Broken Bow—Benton uplift, and it varies greatly in both lithology and thickness within short distances. Miser and Purdue (1929, p. 44) stated that in the Caddo Gap quadrangle the Blaylock sandstone thickens southward from a feather edge to 1,500 feet within 3 miles. Its original thickness and areal extent are unknown, but the Blaylock was probably thicker and covered a larger area than it does presently. Deposition of the Blaylock was into a rapidly subsiding trough south of the present Ouachita Mountains; this trough had a considerable east-west extent and deepened rapidly southward. It is considered that the Blaylock exposed today is merely a thin wedge of post-orogenic sediments resulting from the compression, deformation, and uplift of the early Paleozoic geosyncline located farther southward, and that the coarser-grained and thicker deposits of the Blaylock are south of the present outcrops.

At most places in the Broken Bow—Benton uplift no distinct boundary or stratigraphic break occurs between the Blaylock and Missouri Mountain formations, suggesting that post-Blaylock emergence was of limited extent. In the Black Knob Ridge area and in the Potato Hills, the Missouri Mountain overlaps the Polk Creek formation whose top is eroded at all localities; here, a deepening sea covered areas that were land in Blaylock time. The predominant red and green color of the Missouri Mountain shale, the siliceous nature of many beds, the general absence of fauna, and the small amount of coarse material suggest that the land areas which supplied detritus to this Silurian sea were low-lying and deeply weathered, and that the Missouri Mountain was deposited in relatively deep water in a "starved basin" environment.

Heavy mineral studies of these early Paleozoic rocks also support the theory of a Late Ordovician or Early Silurian orogeny south of the Ouachita Mountains. The sandstones of the Lukfata, Crystal Mountain, Blakely, and Womble formations contain only a few of the heavy minerals most resistant to intrastratal alteration, such as zircon, tourmaline, rutile, magnetite-ilmenite, and leucoxene. Furthermore, the quantity of these minor accessory minerals is unusually low; for example, it is difficult to obtain enough heavy mineral grains from several hundred grams of Crystal Mountain sandstone to make a satisfactory grain count.

The Blaylock sandstone contains abundant heavy mineral grains, but they still belong to the resistant suite. However, Missouri Mountain sandstones contain abundant garnet and some staurolite, with subordinate amounts of zircon, tourmaline, rutile, magnetite-ilmenite, and leucoxene. This strongly suggests a change in provenance from older sediments to rocks of basement complex type, probably accompanying the unroofing of the old source area ("Llanoria"). Star diagrams of the average heavy mineral composition of some of these sandstones have been published elsewhere (Goldstein, 1959a, fig. 1).

Stratigraphic Synopses

In the frontal part of the Ouachita Mountains in Oklahoma, formations of Devonian age include the Pinetop chert and underlying unnamed limestone member and the Woodford chert; part of the Arkansas novaculite in the main anticlinorium of the Ouachita Mountains is also Devonian.

Pinetop chert and limestone.—The Pinetop chert and unnamed limestone are of Middle Devonian age and crop out in the fault block southeast of the Pine Mountain fault. The unnamed limestone is about 20 feet thick but its base is not exposed; the Pinetop chert is about 40 feet thick. The limestone is relatively pure, slightly siliceous, fossiliferous, and lithographic to very finely crystalline. It contains many ostracode carapaces and sponge spicules and a few fragmentary fossils of other types. The Pinetop chert is fossiliferous, sublithographic to very finely crystalline, calcareous, and chalcedonic. It contains colloform veins and nodules of chalcedony.

Woodford chert.—The Woodford chert of Upper Devonian age is exposed at a number of places in Ti Valley in the northern part of the frontal belt of the Ouachita Mountains in Oklahoma. It unconformably overlies the Pinetop chert and is about 67 feet thick. According to Hendricks et al. (1947), the basal 7 feet of the formation is a white chert breccia or conglomerate with lenses of very fine-grained limestone. With the microscope this unit is seen to be intensely fractured and veined calcareous spiculite chert with white opaline silica, scattered carbonate rhombs, and a few radiolarians; this bed is lithologically more like the Pinetop than the overlying Woodford, and it may possibly be an upper breccia in place in the Pinetop rather than reworked Pinetop in a basal conglomerate of the Woodford. H. D. Miser (personal communication, 1959) stated that the Sallisaw and the Penters have a similar breccia at their top; he considered these breccias to be an old rubbly surface whose debris was not reworked by transgressing late Devonian seas.

The part of the Woodford above the chert breccia consists of alternating beds of black sapropelic papery shale with phosphate nodules, and black chert. Conodonts are abundant in the shale beds. In thin section, the cherts are dark red brown, laminated, pyritiferous, and bituminous; they contain numerous spores and a few radiolarians.

Arkansas novaculite.—In the central anticlinorium of the Ouachita Mountains, southeast of the Ti Valley fault, the Arkansas novaculite contains rocks of both Devonian and Mississippian age. The formation has a maximum thickness of 950 feet in Arkansas (Miser and Purdue, 1929, p. 50) but is only 234 to 340 feet thick at Black Knob Ridge, Oklahoma (Hendricks et al., 1947). The contact with the underlying Missouri Mountain shale is reported to be conformable. Hass (1951, 1956) interpreted the lower division of the Arkansas novaculite as Lower or Middle Devonian, the middle division as Upper Devonian and Kinderhook, and the upper division as either uppermost Kinderhook or Osage. The age and correlation of the Arkansas novaculite have also been discussed recently by Ham (1959, pp. 75–76).

The lithology and petrography of the Arkansas novaculite in Oklahoma have been discussed in considerable detail by Goldstein and Hendricks (1953, pp. 428–431). The lowest member at Black Knob Ridge constitutes about half of the formation and consists of white to green massive spiculitic chert and green laminated siliceous shale and metashale or clay-slate. The lower middle member makes up about one-fourth of the entire formation and consists of light gray to black novaculite and black paper shale containing numerous conodonts; the main types of siliceous sediments are bituminous spore-bearing chert, argillaceous radiolarian chert, and radiolarian siliceous shale. The upper middle member constitutes about one-eighth of the formation and is largely red and green radiolarian shale and siliceous to chloritic metashale or clay-slate, with thin beds of radiolarian chert, argillaceous chert, and dark bituminous chert containing both radiolarians and spores. The upper member makes up about one-eighth of the formation and consists of green, brown, and gray, thin-bedded, radiolarian chert, radiolarian shale, and metashale or clay-slate.

In McCurtain County, Oklahoma, and in western Arkansas, the fabric of the novaculite differs considerably from that at Black Knob Ridge, but the rock is similar in composition. In the novaculite from this portion of the Broken Bow—Benton uplift the following differences were noted: (1) cataclastic effects are more widespead and more conspicuous; (2) siliceous fossils are deformed and tend to be resorbed into the cryptocrystalline silica of the matrix; (3) the grain size and crystallinity of the siliceous matrix is greater; and (4) there is a convergence of lithology due to dynamic metamorphism and consequent recrystallization. New lithologic types in the novaculite of this area include a calcareous novaculite with relict rhombs of manganiferous carbonate which forms much of the upper member, and a widespread fine-grained breccia or conglomerate consisting largely of granule- and sand-size particles of various types of chert, siliceous shale, and quartz grains.

Formations of Mississippian age in the central anticlinorium of the Ouachita Mountains include part of the Arkansas novaculite, the Hot Springs sandstone, all of the Stanley shale (Hass, 1950, 1956; Cline, 1956a, 1956b), all of the Jackfork sandstone (Hass, 1956; Cline, 1956a, 1956b; Cline and Shelburne, 1959), and part of the Johns Valley shale (Cline and Shelburne, 1959, p. 207). The complex stratigraphic relations, the scarcity of marine invertebrates, and the necessity of working with such little-known fossils as Paleozoic radiolarians, conodonts, sponge spicules, and plant fragments have resulted in uncertainty and controversy regarding the age of these clastic sediments.

Caney shale and Sycamore(?) limestone.—In the frontal part of the Ouachita Mountains in Oklahoma, between the Choctaw and Ti Valley faults, sediments of Mississippian age are the Caney shale and beds possibly equivalent to the Sycamore limestone. The Caney unconformably overlies the Woodford in Ti Valley, where it is about 525 feet thick and consists of dark-colored shale, hard and siliceous at places but soft and flaky elsewhere. Septarian nodules are common in some parts of the formation. The fauna of the Caney consists largely of cephalopods, pelecypods, and conodonts. The possible equivalent of the Sycamore limestone is present at the base of the Caney and comprises grayish-green shale with abundant conodonts, phosphatic concretions, and glauconite.

Hot Springs sandstone.—The Hot Springs sandstone of Early Mississippian age is exposed only in and near Hot Springs, Arkansas, where it is as much as 200 feet thick. The formation is primarily sandstone, with subordinate amounts of shale and conglomerate; it unconformably overlies the Arkansas novaculite and grades into the overlying Stanley shale. The Hot Springs sandstone is well sorted, very fine to fine grained, and quartzose. In the cleaner, clay-free sandstones there is little indication that the rocks have been subjected to metamorphism, although the quartz grains are "welded" together very tightly with secondary silica and the original outlines of the quartz grains are obscure and poorly defined. However, rocks which contained small to moderate amounts of original interstitial argillaceous material show definite weak to low-grade metamorphism. The interstitial clay has been reconstituted almost completely into chlorite and sericite, and many of the detrital shale grains have been altered into nests of intercrystallized chlorite, sericite, and cryptocrystalline quartz.

Stanley shale.—The Stanley shale is one of the thickest and most widespread formations in the Ouachita Mountains region. It is about 6,000 feet thick in western Arkansas and McCurtain County, Oklahoma, and as much as 12,000 feet thick in the southeastern part of the area mapped by Hendricks and others (1947) in Oklahoma. Hass (1956) tentatively placed the Mississippian-Pennsylvanian contact within the Stanley shale, but Cline (1956b) and Cline and Shelburne (1959) concluded that the Stanley is entirely of Mississippian age. The contact with the underlying Arkansas novaculite is unconformable in some areas (Miser and Purdue, 1929; Hendricks et al. 1947), but Honess (1923) thought it was conformable and possibly transitional in McCurtain County. In the Walnut Creek section in the Potato Hills, where the contact of the Stanley and Arkansas novaculite is well exposed, there are beds of very fine-grained argillaceous sandstone and siltstone which closely resemble similar sandstones in the lower Stanley but are here overlain by typical novaculite, suggesting a gradation between the formations. Hendricks et al. (1937, pp. 11–12) noted that the contact between the two formations appeared to be gradational in most exposures in the Black Knob Ridge area but postulated that the upward gradation from the novaculite to the Stanley is due to the presence in the basal Stanley of abundant mechanically and chemically reworked siliceous material from the novaculite. The contact is apparently conformable in most of the localities sampled by the writer.

Any discussion of the stratigraphy of the Stanley shale must be generalized, owing to the complexity of structure, poor resistance of the beds in most outcrops, scarcity of marker beds, and the great thickness of the formation. An undisturbed, continuous, and measurable section of the Stanley shale is not known, although composite sections can be assembled.

In the Black Knob Ridge area of Oklahoma, the basal beds of the Stanley are hard, green to buff siltstone and shale. Some of the siltstone is cherty and has a siliceous cement. Above the basal beds the Stanley is largely green to gray clay shale, alternating with beds of greenish siltstone and very fine-grained sandstone as much as 100 feet thick. Sandstone (or siltstone) alternates regularly with shale beds, with sharp contacts at tops and bottoms; bedding features due to wave action are uncommon but flutings and striations formed by density (turbidity) currents and mud flows are abundant; intra- and interstratal flowage features are widespread (Bokman, 1953, pp. 153–156). The siltstones and sandstones are typically fine grained and argillaceous; pockets, streaks, and detrital fragments of shale and metashale occur in the sandstones at places. At several horizons in the Stanley in Oklahoma there are beds of blue-gray to black siliceous shale from 15 to 75 feet thick; a bed of variegated, red and green clay shale is present in the upper part of the formation. Cone-in-cone structure is common in calcareous concretions and in abundant thin layers of calcareous material at many horizons. The shales and siltstones contain much fragmental plant material; the siliceous shales contain spores, spicules, radiolarians, and conodonts. Sandstone dikes up to 2 feet wide are fairly common in the Moyers siliceous shale.

Petrographically, the Stanley shales near Black Knob Ridge are composed of varying amounts of illitic clay minerals, quartz silt, sericite, chlorite, carbonaceous material, detrital micas, and cryptocrystalline silica. Radiolarians, spores, pyrite, hydrous iron oxides, and glauconite are present locally. The clay minerals in the shales are unaltered to slightly reconstituted. The typical sandstone from this area is poorly sorted, argillaceous, chloritic, and very weakly metamorphosed to unmetamorphosed. The detrital grains are angular to subrounded and range in size from medium sand to medium silt. Quartz is most abundant, but there are numerous detrital grains of chert, potassic feldspar, quartzite, shale, and sodic plagioclase feldspar. These detrital grains are embedded in a "mud" matrix which has been reconstituted in part into new chlorite and sericite. Microscopic folds and faults and tiny veinlets of quartz are abundant. The petrography of the siliceous shales has been discussed in detail by Harlton (1938) and by Goldstein and Hendricks (1953); they are thinly laminated, carbonaceous or bituminous, pyritic, and contain a meager and restricted fauna of siliceous, chitinous, and phosphatic organisms.

In most of the Broken Bow—Benton uplift (Miser, 1959), the Stanley shale is largely shale and sandstone, with subordinate amounts of slate, siliceous shale, tuff, chert, cone-in-cone concretions, and phosphate rock. The major difference between the rocks of this area and those near Black Knob Ridge is the widespread weak to low-grade metamorphism of both the argillaceous and arenaceous rocks. The "shales" of the Stanley in the central anticlinorium are mostly clay-slate and slate. They consist of chlorite, quartz silt, sericite, cryptocrystalline silica, carbonaceous material, and small amounts of clay minerals; much of the original argillaceous material has been reconstituted. The Stanley sandstone (metasandstone) from McCurtain County contains more cataclastic structures than sandstone from Black Knob Ridge, and the interstitial "mud" matrix is more completely reconstituted into new chlorite and sericite. At places the quartz grains have a corroded appearance, probably from reaction with the mud matrix during metamorphism and the formation of new chlorite and sericite. Alignment of the long axes of elongate quartz grains, microscopic folding and faulting, and intrusion of quartz veinlets into the sandstone are common (Pl. 6, A).

An acidic crystal-vitric tuff, the Hatton tuff lentil, is extensive in the Stanley formation in McCurtain County, Oklahoma, and in western Arkansas (Miser and Purdue, 1929; Honess, 1923; Goldstein and Hendricks, 1953). Other tuffs which may or may not be correlative crop out in the Stanley near the Potato Hills, and sandy tuff and tuffaceous sandstone have been found in the Stanley in cuttings from several wells in southeastern Oklahoma.

Jackfork sandstone.—The Jackfork sandstone conformably overlies the Stanley shale throughout the Ouachita Mountains. Most of the Jackfork contains only poorly preserved plant fossils, conodonts, radiolarians, *Orbiculoidea*, and a few goniatites, although Honess (1924) obtained a Morrow fauna from sandstone in the northwest part of McCurtain County, Oklahoma, which were originally termed Jackfork(?) but were later referred to the Atoka. Most paleontologic evidence has been interpreted as indicating that the Jackfork is of Lower Pennsylvanian age (Hass, 1956), but Cline (1956b) and Cline and Shelburne (1959) believed it to be of Mississippian age.

In the Ouachita Mountains, the Jackfork sandstone is about 1,150 feet to as much as 7,000 feet thick. Two complete and unfaulted sections in the Kiamichi Mountains were measured by Cline and Moretti (1956) and are 5,600 and 6,000 feet thick.

In the Black Knob Ridge area the Jackfork is predominantly sandstone with intercalated shale. Four persistent beds of siliceous shale have been identified, and there is one zone of maroon to green shale and buff siltstone near the top of the lower third of the formation (Hendricks et al., 1947).

The fresh sandstone varies from white through gray to blue, and most of it is fine to medium grained. Much of the sandstone is massive to thick bedded but part is thin bedded. Some conglomerate beds are present locally in the middle part of the Jackfork. No systematic variation in grain size can be observed within individual beds, and the thicker beds do not appear coarser than the thinner. Ripple marks, sole markings, laminations parallel to the bedding, and small-scale cross-laminations are widespread, but large-scale cross-bedding is unknown (Bokman, 1953, p. 157).

The maroon shale and siliceous shale zones of the Jackfork in Oklahoma permit subdivision of the formation and also constitute the most reliable means of identifying it in outcrop. Two of the siliceous shale beds contain erratic boulders as much as 7 feet in diameter (Hendricks et al., 1947). Most of the other shales in the Jackfork are light to dark gray, laminated, generally fissile, and are of little use as marker beds.

The Jackfork sandstones in the western part of the Ouachita Mountains in Oklahoma are "dirty" quartzose sandstones and subgraywackes; they are low in feldspar with an introduced mineral cement (mostly silica). A typical sandstone is ferruginous to chloritic, argillaceous, fairly well sorted, and fine grained. Most detrital grains of quartz, chert, quartzite, shale, and feldspar are subangular to subrounded. Some laminae consist largely of minor accessory minerals, and in some beds there is complete secondary silica cementation. The rocks are not metamorphosed near Black Knob Ridge, and most of the interstitial "clay" has not been reconstituted into chlorite and sericite. In general, the Jackfork sandstones are less argillaceous, better sorted, coarser grained, contain fewer quartz veinlets, and show less cataclastic structures than Stanley sandstones from this same area. The clay shales interbedded with the sandstones are similar petrographically to those in the Stanley. The siliceous shales of the Jackfork (Harlton, 1938; Goldstein and Hendricks, 1953) are irregularly laminated, color banded, and wavy bedded; they consist largely of "clay," silica, carbonaceous and/or bituminous material, quartz silt, micas, pyrite, and chlorite. Radiolarian capsules and spines, sponge spicules, and spore exines are the major faunal elements, although fragments of calcareous fossils occur at places. Intraformational chert breccias occur in some of the siliceous shale beds.

In the Broken Bow—Benton uplift, the Jackfork generally contains more sandstone, mostly in massive thick ledges. Most of these rocks show some reconstitution of interstitial argillaceous material into new chlorite and sericite; most are poorly sorted and cemented with silica. Quartz is still the dominant detrital component, although polygranular (rock) grains such as chert, quartzite, quartz schist, shale, slate, and phyllite are fairly common.

Johns Valley shale.—The Johns Valley shale overlies the Jackfork sandstone but is preserved only intermittently in a strip of territory 20 miles wide and 25 miles long in the northwest part of the Ouachita Mountains. The lower contact is apparently conformable at most places, but in the northwestern part of the area the Johns Valley overlaps strata in the upper part of the Jackfork sandstone.

The Johns Valley shale is from 200 to about 1,000 feet thick. Many investigators have concluded that it is of Early Pennsylvanian (Morrowan) age, but recent work by Cline and Shelburne (1959) indicates that the formation bridges the Mississippian-Pennsylvanian time line, containing rocks of Caney age in its lower part and rocks of Springer and Wapanucka age in its upper part.

The Johns Valley shale consists of clay shale and clay, thin beds of sandstone, a few lenses of limestone, abundant erratic granules, pebbles, cobbles, and boulders, and some very large erratic masses of various kinds of sedimentary rocks. Most of the shale is light gray to tan, but it is generally dark gray near the base of the formation. Differential thermal analyses indicate that illite is the main clay mineral in Johns Valley shales. The sandstones are fine to very fine grained, poorly sorted, and argillaceous; ripple marks are common and some sandstones are calcareous and fossiliferous. The interstitial clay minerals in the sandstones are essentially unaltered. The lenses of limestone in the formation are coarsely crystalline, impure, fossiliferous, and locally conglomeratic.

The erratic boulders in the Johns Valley shale are mostly rounded pieces of limestone, chert, shale, sandstone, and phosphatic nodules. The large erratic masses are generally angular and consist of limestone and shale. A few known limestone masses are more than 100 feet long. Masses of Caney shale in the lower part of the formation many hundred feet long have been considered to be erratic masses. However, Cline's recent work indicates very strongly that many, if not all, of these masses may be remnants of an eroded surface of Caney shale in its correct stratigraphic position. The erratic pebbles, cobbles, and boulders range in age from Cambrian to Mississippian, inclusive; boulders of Pennsylvanian age, doubtfully considered erratic, have also been described (Miser, 1934b). Both the boulders and the large erratic masses are of rocks of foreland facies, characteristic of such areas as the Arbuckle Mountains or Ozark uplift. The large erratic masses have been reported only from the basal part of the Johns Valley shale, whereas erratic boulders up to 25 feet long occur at numerous horizons in the formation (Hendricks et al., 1947).

The origin and transportation of the erratic boulders in the Johns Valley shale has been one of the most controversial problems in the Ouachita Mountains. Cline and Shelburne (1959, pp. 193–204) have discussed the Johns Valley shale most comprehensively, giving details and references for most of the hypotheses that have been advanced. They concluded that most of the boulders were brought to their depositional site by ice-rafting, although some of the large erratic masses may have been transported by submarine slides or slips, a theory suggested originally by Miser (1934b). P. B. King (personal communication, 1959) suggested that the boulder beds are related to normal or high-angle faulting at the margin of the Ouachita geosyncline, accompanying the rapid deepening of the orogenic phase. The writer's own opinion, based on very limited field study in the Ouachitas and in the Haymond boulder beds of the Marathon uplift, is that some tectonic origin connected with orogenic activity in the Ouachitas is required for a source, but that normal sedimentary processes such as mud flows and submarine slumping have transported and redistributed the erratic boulders.

Pennsylvanian formations in the central anticlinorium of the Ouachita Mountains include part of the Johns Valley shale (as previously discussed) and the Atoka formation. In the frontal zone of the western part of the Ouachita Mountains in Oklahoma, between the Choctaw and Ti Valley faults, the Pennsylvanian consists of the Springer formation of Early Pennsylvanian age, Wapanucka limestone and Chickachoc chert of Early Pennsylvanian (Morrowan age), and Atoka formation of early Middle Pennsylvanian age. The exact age and correlation of some of the frontal zone "Atoka" is uncertain.

Springer formation. — Sediments referred to the Springer formation are present in fault blocks southeast of the Choctaw, Katy Club, and Pine Mountain faults. The best exposures are in the blocks southeast of the Choctaw fault and southeast of the Pine Mountain fault.

Southeast of the Choctaw fault the Springer conformably overlies the Caney (Mississippian) shale. In this area the Springer is probably about 2,500 feet thick, and it is largely shale with subordinate siltstone. The shale is dark gray, gritty, micaceous, and weathers into spheroidal masses that disintegrate into small flakes. Thin beds and concretions of siderite are widespread. In the upper part of the formation are beds of tan, calcareous siltstone, weathering light gray. Both the microfauna in the shale and occasional larger fossils indicate an Early Pennsylvanian age, and these strata are probably equivalent to the Springer formation in the Arbuckle Mountain region.

Wapanucka limestone. — The Wapanucka limestone of Early Pennsylvanian (Morrowan) age is exposed southeast of the Choctaw fault in the frontal part of the Ouachita Mountains. In this fault block the Wapanucka is probably conformable on the Springer. The Wapanucka varies greatly in thickness in short distances, ranging from 270 feet to about 720 feet. Individual beds vary in lithologic character within short distances, and sections measured a mile apart are difficult to correlate in detail.

The Wapanucka may be divided broadly into four units. The lowest unit comprises alternating shale and spicular limestone beds and is from 60 to 320 feet thick. The shale is gray, clayey, calcareous, and weathers tan. The limestone beds are dark gray, finely crystalline, very siliceous, contain abundant sponge spicules, and weather light gray to buff. Thin sections show the mixed nature of the sedimentation of this unit; the lithologic types are chert, limestone, sandstone, siltstone, and shale, but all of the rocks are impure. The cherts are limy and silty; the sandstones and siltstones contain abundant argillaceous material, calcite, and glauconite. Sponge spicules are distributed widely through all lithologic types, being completely silicified in some specimens, partly silicified in others, and replaced by glauconite in a few.

The second unit from the base is generally ledge-forming and as much as 120 feet thick, although it may be absent locally. It consists of (a) dark gray, finely crystalline, platy limestone; (b) calcareous medium-grained sandstone; and (c) dark gray, compact, spicular, locally oolitic limestone, all of which are interbedded with gray calcareous shale that weathers tan. The third unit is 60 to 250 feet thick and consists of gray, calcareous clay shale that weathers tan with local development of thin lenses of brown conglomeratic and glauconitic limestone.

Thin sections of limestones from the middle two units of the Wapanucka are mostly microcoquinas containing a variety of rounded and abraded fossil fragments, including corals, bryozoans, gastropods, bivalves, and foraminifers. Some of the rocks contain true multi-ringed ooliths, but pseudo-ooliths consisting of a single band of lithographic calcite surrounding a fossil fragment are more common. The matrix of these clastic limestones is clear, finely crystalline to sublithographic calcite. Phosphate pellets, pyrite, and glauconite are fairly common. The cherts and siliceous limestones of the middle two units are more silty than the limestones and nearly all contain sponge spicules. Both calcareous and silicified spicules can be observed in the same sample. Most of the carbonate is anhedral and sublithographic to finely crystalline. Most of the chert matrix is cryptocrystalline silica rather than chalcedony.

The fourth or upper unit of the Wapanucka is the principal ridge-forming member, and it is from 60 to 170 feet thick. The lithology of this unit varies greatly, but at most places there is a lower, dark gray, siliceous and oolitic limestone which grades laterally into coarse-grained, calcareous, brown to buff sandstone. Above it is light gray limestone, non-siliceous, compact to finely crystalline, pseudo-brecciated, and very irregularly bedded. At the top is generally a bed of hard, black, spicular chert from 2 to 10 feet thick.

Thin sections of the upper unit show a definite relationship between the type of fauna and the silica content of the rock; presumably this relates also to the environment at the time of deposition. The pure limestones of the upper unit contain abundant fragmentary megafossils, ostracodes, foraminifers, and pellets (algal?) in a matrix of lithographic to sublithographic limestone. The calcareous cherts and silicified limestones contain foraminifers, ostracodes, silt, sand, and glauconite but also contain numerous partially silicified to completely calcareous sponge spicules. The noncalcareous cherts consist almost entirely of a mass of silicified monaxon sponge spicules in a dark gray matrix of cryptocrystalline silica, argillaceous and carbonaceous material, pyrite, and glauconite.

Chickachoc chert.—The Chickachoc chert of Lower Pennsylvanian (Morrowan) age crops out in the fault block southeast of the Katy Club fault in the frontal part of the Ouachita Mountains of Oklahoma. The Chickachoc overlies the Springer shale, but the nature of the contact is uncertain (Hendricks et al., 1947); it is overlain by the Atoka formation with apparent conformity.

The Chickachoc chert is as much as 600 feet thick. It is mostly greenish-gray to tan clay shale that weathers to a tan clay, but it also includes about ten beds and lenses of spiculite. The spiculite is a mass of sponge spicules cemented by siliceous limestone; where fresh the spiculite appears to be compact, blue-gray, siliceous limestone, but where weathered the carbonate is leached and it resembles a porous chert or sandstone. The base of the formation is at the base of the lowest spiculite bed; another bed 20 to 50 feet thick is in the middle of the formation, and a very massive spiculite bed forms the top member of the formation.

The lower unit of alternating spiculite and shale is very similar to the lower Wapanucka, but the spiculite beds are less calcareous. The middle spiculite beds correspond to the lower limestone unit of the Wapanucka, and the upper spiculite bed corresponds to the upper limestone unit of the Wapanucka.

Thin sections of the Chickachoc chert, mostly from the more resistant beds, range from fossiliferous, nonsiliceous limestone through calcareous chert to noncalcareous chert. Almost all of the rocks contain abundant monaxon sponge spicules of the same type, but they are wholly calcareous in the nonsiliceous limestone, are partly silicified in the calcareous cherts, and are completely silicified in the noncalcareous cherts.

The nonsiliceous limestones in the Chickachoc are inequigranular, fossiliferous, and lithographic to sublithographic. They contain calcareous spicules, foraminifers, and fragmentary crinoids and bryozoans. Quartz silt, argillaceous material, iron oxide and pyrite are common impurities; glauconite, phosphate pellets, and sand-size quartz grains are fairly common.

Most of the resistant beds in the Chickachoc chert are inequigranular, fossiliferous, calcareous chert and siliceous limestone intermediate between the two end members. Foraminifers, ostracodes, and sponge spicules are abundant, but fragmentary megafossils are not as abundant as in the nonsiliceous limestones. Most of the silica is yellowish to brown chalcedony; in some samples it can be seen that the chalcedony preferentially replaces the matrix, elsewhere chalcedony replaces carbonate matrix and sponge spicules indiscriminately, whereas in other specimens the silica is concentrated in the spicules. The impurities in these rocks are the same as in the nonsiliceous limestones.

The noncalcareous cherts are almost entirely a felted mass of silicified sponge spicules, with some interstitial "clay," carbonaceous material, and pyrite. In some specimens the spicules have been "chertified" and incorporated into a solid mass in which the outlines of the individual spicules are only faintly visible in plane transmitted light. Other fossils are rare or lacking.

Atoka formation.—The Atoka formation of Early to Early Middle Pennsylvanian age is one of the most variable formations in the Ouachita Mountain region; there are distinct changes in lithology, texture, and thickness of beds within short distances. Furthermore, dissimilar units have been termed "Atoka" in the central anticlinorium of the Ouachita Mountains, near Black Knob Ridge and the Potato Hills, in the thrust-faulted frontal zone of the Ouachita Mountains, and in nearby foreland areas such as the McAlester basin. Additional confusion has been created by the use of "Atoka" as both a lithogenetic unit (formation) and as a time-stratigraphic unit (for example, as a fusulinid zone). The type locality of the Atoka formation is at the town of Atoka, at the south end of Black Knob Ridge, Oklahoma, but the fauna at the type locality is sparse and largely nondiagnostic.

The Atoka of the Ouachita Mountains southeast of the Ti Valley fault is discussed first, followed by discussions of "Atokan" sediments in each of the fault blocks progressively north and northwest of the Ti Valley fault.

In most of the western part of the Ouachita Mountains, southeast of the Ti Valley fault, the Atoka formation overlies the Johns Valley shale. At most places the contact is conformable, but in the northwestern part of the area the Atoka overlaps the

Johns Valley shale and rests on strata in the upper part of the Jackfork sandstone (Hendricks et al., 1947). In most of western Arkansas, the Atoka overlies the Jackfork sandstone with apparent conformity (Miser and Purdue, 1929, p. 78).

In the western part of the Ouachita Mountains in Oklahoma, the Atoka is the youngest Paleozoic formation preserved and its top is either eroded or cut off against a thrust fault. The full thickness of the formation is thus unknown, but more than 4,000 feet is exposed at places. The formation is mainly light gray, silty, micaceous, flaky shale, with lenses and beds of sandstone. The sandstone is tan to buff, very fine to medium grained, locally ripple marked and micaceous, exhibits abundant sole markings, and forms well-marked beds a few inches to several feet thick. Thin sections indicate that most of these sandstones are poorly sorted, micaceous, and moderately argillaceous. Many specimens contain anhedral grains of very finely crystalline to sublithographic carbonate, which is uncommon in both Stanley and Jackfork sandstones. Besides the dominant quartz, Atoka sandstones generally contain chert grains, potassium and plagioclase feldspar, detrital flakes of muscovite and biotite, detrital shale, and hydrous iron oxides. In some specimens the interstitial argillaceous material and the detrital shale fragments have been almost completely reconstituted into new chlorite and sericite, whereas the "clay" in other sandstones shows only incipient reconstitution and the rocks would have to be classified as unmetamorphosed. Atoka sandstones of the central anticlinorium of the Ouachita Mountains in McCurtain County, Oklahoma, and in western Arkansas are generally very weakly to weakly metamorphosed.

About 200 feet above the base of the Atoka in the western part of the Ouachita Mountains in Oklahoma is a bed of black siliceous, conodont-bearing shale, about 1 foot thick. This bed is overlain by a bed about 2 feet thick that is banded light and dark gray and consists of alternating layers of siliceous shale and sponge spicules. About 2,000 feet above the base of the formation is a 4-foot bed that consists of alternating bands of sponge spicules and sand grains (Hendricks et al., 1947). The lower Atoka siliceous shale is largely dark-colored, carbonaceous, spiculitic siliceous shale and silty to sandy spiculite chert. Well-preserved radiolarians occur in many specimens but are subordinate to the sponge spicules. Glauconite, pyrite, graphite(?), and phosphate grains are present at places (Goldstein and Hendricks, 1953, p. 434).

In the frontal part of the Ouachita Mountains, sedimentary rocks called "Atoka" occur in all three of the major fault blocks. Most of these rocks do not contain diagnostic fossils, and it is possible that all may not be of Atokan age nor of exactly the same age.

Southeast of the Pine Mountain fault, the Atoka overlies the Springer unconformably; the Atoka is poorly exposed but is probably about 5,000 feet thick. It is largely shale with scattered lenses of sandstone as much as 10 feet thick which form about 10 percent of the unit. Most of the shale is gray to brown, silty, poorly laminated and soft; some shale is greenish gray, clayey, and flaky; and a few beds are black, clayey, and carbonaceous. The sandstone is gray to brown, soft, micaceous, limonitic, and fine to medium grained. Fragmental plant material is abundant in both the shale and the sandstone.

In the fault block southeast of the Katy Club fault the Atoka formation conformably overlies the Chickachoc chert. The top of the Atoka is everywhere cut by a thrust fault but thickness is probably on the order of 5,000 feet. The lower 1,000 feet is mostly black to gray clay shale with scattered lenses of sandstone. This basal zone is overlain by about 3,500 feet of alternating sandstone and shale in about equal amounts. The shale is gray, clayey to sandy, and contains fragmental plant material at most places. The sandstone is medium to coarse grained, white to pale buff, and weathers brown. The uppermost 500 feet of the Atoka is similar to the basal zone but more sandy.

Southeast of the Choctaw fault the Atoka is about 9,000 feet thick. The greater thickness results from addition of strata to the upper part of the formation that are not preserved southeast of the Katy Club fault. These additional beds are gray, silty, micaceous shale containing lenses and a few beds of hard, micaceous, ferruginous medium-grained sandstone. Near the town of Atoka, the sandstone beds are conglomeratic and contain pebbles as large as 4 inches in diameter, including fragments of Chickachoc chert and phosphatic nodules from the Caney shale (Hendricks et al., 1947).

Thin sections of Atoka sandstones from the frontal belt show considerable lithologic variation, but the collections are too limited to establish criteria for separating the Atoka of the various thrust blocks from one another. Most of the sandstones are poorly sorted but some are well sorted. The median grain size of these rocks ranges from fine sand to coarse silt. Most of the sand grains are subrounded to subangular, with few extremes of either roundness or angularity. Quartz is the dominant mineral, but micas and polygranular fragments such as chert, quartzite, shale, and metamorphic rock grains are abundant locally. A wide variety of feldspars occurs, although they rarely total more than 3 to 4 percent of the rock. The sandstones are weakly to moderately well cemented with either silica or clay binding material. The rocks are unmetamorphosed; the interstitial "clay" shows little reconstitution, and quartz veining and cataclastic structures are generally minor or even absent.

Stratigraphic Analysis

At the beginning of the Devonian period, widespread shallow seas probably bordered a low-lying landmass ("Llanoria") south of the Ouachita Mountain area. The amount of clastic detritus supplied to the seas north and west of the source area was very small.

Devonian-Mississippian volcanism south of the Ouachita geosyncline resulted in extensive ash falls into the shallow seas that were nearly free of other clastic detritus. Submarine weathering of these pyroclastic sediments, prolonged over long periods of time, removed readily soluble elements and converted the ash to nearly pure opaline silica. Radiolarians and siliceous sponges thrived in the high-silica environment, and their remains are preserved in the siliceous sediments. A normal marine environment obtained during most of this time, and fossiliferous marine limestones (upper Hunton, Pinetop) were deposited in foreland areas where less pyroclastic material was being laid down. Occasionally, stagnant bottom conditions prevailed in the axial and distal portions of the geosyncline, and sapropelic high-silica sediments containing spore exines (middle Arkansas novaculite—Woodford) were deposited. Intermittent uplift and accompanying increases of stream gradient caused the deposition of clastic detritus far out in the geosyncline and resulted in the interbedded shales and thin sandstones found in the Arkansas novaculite. Some parts of the upper novaculite were probably laid down in subaerial or tidal-flat conditions, as indicated by the presence of some silicified wood in large pieces and stumps several feet in diameter, some of which are apparently in growth position.

Near the middle of Mississippian time the volcanism gradually diminished, although sporadic paroxysmal outbursts were yet to come. In Arkansas and in parts of Oklahoma, the sea retreated and the land was exposed to subaerial erosion. North of the DeQueen and Caddo Gap quadrangles and in the northern part of the Hot Springs district, Arkansas, the novaculite strata were planed off (Miser and Purdue, 1929, p. 132). After this brief period of erosion, a bed of pebbles was laid down in many parts of Arkansas, succeeded locally by the well-washed, quartzose Hot Springs sandstone. This sandstone was not extensive, so that in most of the Ouachita Mountains the basal deposits of the Stanley shale directly overlie the Arkansas novaculite.

Towards the middle or end of Mississippian time, a period of crustal mobility was initiated and active downwarping occurred along the entire Ouachita geosyncline. The sluggish streams draining the region were rejuvenated, and large amounts of clastic detritus were poured into the trough. Much of the Stanley may have been deposited by sediment flows so dense that little water was entrained and minimum turbulence was developed; these sediment flows probably moved westward down the axis of the trough. Concurrent with the geosynclinal downwarping, there was uplift of land masses to the south of the Ouachita Mountain region in north Louisiana and east Texas. The northern margins of these source areas were covered with previously deposited pre-Stanley sediments which now were eroded and carried out into the geosyncline, and a considerable period of time may have elapsed before crystalline rock detritus from the basement complex was supplied to the Ouachita geosyncline.

Intermittent eruptions supplied small amounts of volcanic ash to the geosyncline through much of Middle and Late Mississippian time, and at least one major eruption occurred subsequent to the deposition of the Arkansas novaculite. This formed the Hatton tuff lentil in the lower part of the Stanley shale. The Hatton tuff lentil is an acidic crystal-vitric tuff probably similar to the parent material of the cherts and novaculites, but the Hatton tuff was laid down during active downwarping, so that it was buried quickly by clastic sediments, was not exposed to prolonged submarine weathering, and was never converted to chert. Other minor volcanic episodes, possibly accompanied by brief hiatuses in the supply of coarser clastic sediments, resulted in the siliceous shale beds of the Stanley and Jackfork formations.

Deposition was relatively continuous throughout the Stanley-Jackfork sequence, with only minor diastems. The Stanley is the orogenic, deep-water flysch facies of the late Paleozoic Ouachita geosyncline, in which large amounts of clastics were poured into a rapidly subsiding geosynclinal trough; the typical deposits of this facies are dark shale and graywacke sandstone without graded bedding and with few sole markings. As the geosynclinal trough filled up and migrated towards its foreland, the deep-water flysch facies was succeeded by a shallower-water flysch facies in the Jackfork and Atoka formations in which the sandstones (subgraywacke and protoquartzite) are coarser, cleaner, cross-bedded, and contain abundant sole markings.

The flood of garnet which appeared in the heavy mineral assemblages of Missouri Mountain sandstones persists in the thin sandstones of the Arkansas novaculite and diminishes in Stanley sandstones; it is replaced in Jackfork sandstones by the highly resistant suite of minerals (mostly zircon, tourmaline, rutile, ilmenite-magnetite, and leucoxene) characteristic of Blaylock and older sandstones. Bokman (1953) noted the flood of garnet in Stanley sandstones from areas west of McCurtain County and the virtual absence of this mineral in sandstones of the Jackfork formation; he concluded that the Stanley was a first-cycle sediment derived from a source composed primarily of igneous and other crystalline rocks, whereas the Jackfork strata were derived principally from metasediments.

Analysis of unpublished heavy mineral studies of Ouachita Mountains sandstones by Winland (1953) strongly suggests another possibility, namely, that the borderland of crystalline rocks south of the Ouachita Mountains was stripped of its sedimentary cover in Late Ordovician or Early Silurian time, and that this source area contributed fresh detritus at intervals through Late Silurian, Devonian, and Early Mississippian time. By the middle of Stanley time and throughout the deposition of the Jackfork strata, most of the sedimentary detritus supplied to the Ouachita geosyncline was being derived by erosion, transportation, and redeposition ("cannibalization") of uplifted previously deposited geosynclinal sediments in interior foldbelts. Erosion of the youngest sediments would contribute much second-cycle garnet; when the pre-Missouri Mountain sediments were eroded, only the resistant multi-cycle heavy minerals of the older sandstones would be available for redeposition. These factors may account for the abundant garnet in Lower Stanley sandstones and the paucity of garnet in Jackfork sandstones.

While the Stanley-Jackfork sequence was being laid down in the axial portion of the geosyncline, deposition was proceeding simultaneously in the distal portion of the geosyncline, out towards the foreland. The Upper Mississippian in this area is the Caney shale, a calcareous marine shale with septarian nodules and thin intercalated limestones, which overlies Sycamore or Woodford. Hard blue-gray siliceous shale beds in the Caney lithologically similar to those in the Stanley-Jackfork may represent thin shelf remnants of modified ash falls. The Caney is succeeded by the shales and sandstones of the Springer formation, which is considered to be of earliest Pennsylvanian age.

A short but widespread period of relative quiescence and less abundant clastic detritus succeeded Jackfork deposition throughout the Ouachita geosyncline. In the axial portion of the geosyncline, the Johns Valley shale was laid down; the Chickachoc limestone was deposited farther out in the distal portion of the geosyncline, and the Springer formation and the Wapanucka limestone were laid down marginal to the geosyncline and in the foreland areas. All these formations contain a calcareous marine fauna.

Uplift and possible thrust faulting in Morrow(?) time caused some erosion and redeposition of the older sediments. Exotic boulders from faulted foreland areas, principally of Arbuckle-type rocks and Ozark-type rocks, were transported into the Ouachita Mountain region and laid down in the mudstone of the Johns Valley shale. Cline (1959) stated that the Johns Valley shale represents the "wild flysch" of Alpine geologists. The sediments of the Ouachita geosyncline were squeezed and deformed in the early stages of the orogeny that culminated in the structures of the Ouachita Mountains.

With the beginning of Atoka time, late orogenic and early post-orogenic deposition began in this region, resulting in heterogeneous, lithologically diverse clastic sediments which change character rapidly within short distances. Rhythmic alternation of thin-bedded sandstones and shale, such as is characteristic of much of the Haymond (Atokan) of the Marathon region, is absent or poorly developed.

Structural movement and uplift of the Ouachita Mountains began in late Atoka time and continued concurrently with the progressive downwarping of the Desmoinesian basin to the north. As the pre-Atoka geosynclinal sediments were uplifted, eroded, and redeposited farther out in the basin, the axis of the active geosyncline migrated northward and westward over the foreland, into the areas of the McAlester and Fort Worth basins. Conglomerates in the Thurman sandstone and involvement of beds as young as Boggy shale (and possibly the Thurman sandstone) in Ouachita Mountains folding indicate that structural movement definitely continued as late as middle Desmoinesian time; it is possible that folding and minor faulting were more or less continuous throughout the Pennsylvanian. The folding and faulting were produced by horizontal compressive movements acting in a nearly north-south direction.

Some overthrusting may have occurred by the end of Atoka time, particularly in the interior foldbelts of the Ouachita system, but most of the thrusting in the frontal part of the system appears to have occurred in Middle or Late Pennsylvanian time, culminating in the major thrusting of the Ti Valley and Windingstair faults. Epeirogenic uplift occurred in the Permian (Van der Gracht, 1931a) when the deformation of the Ouachita geosyncline was essentially completed.

Since Middle Pennsylvanian time, much of the Ouachita Mountains region has been either emergent or only partly submerged and subject to almost continual erosion. Some areas may have had as much as 18,000 feet of strata stripped from them (Miser and Purdue, 1929, p. 136). Other major geologic events in this region include the formation of two successive peneplains, the overlap of the Lower and Upper Cretaceous seas upon the region, and one or more periods of intrusion of ultrabasic and basic igneous rocks in Cretaceous time. During Tertiary and Quaternary time the region was subjected mostly to differential erosion and dissection, which has resulted in the present topography.

STRUCTURE OF THE OUACHITA MOUNTAINS

Central Anticlinorium

The principal anticlinal fold of the Ouachita Mountains extends from Benton, Arkansas, west-southwest to Broken Bow, Oklahoma, and has been named the Broken Bow–Benton uplift (Miser, 1959, p. 32). This anticlinal fold is not simple but is a compound anticlinorium composed of several anticlinoria and intervening synclinoria. Honess (1923, pp. 213–261) found two anticlinoria separated by a synclinorium in the central part of his map area, the Choctaw anticline to the west and the Cross Mountains anticline to the east, separated by the Linson Creek syncline. Honess' central anticlinorial area is mostly in McCurtain County, Oklahoma, extends only 12 miles into Arkansas, and forms only the western part of Miser's Broken Bow–Benton uplift.

Along the higher parts of the central anticlinorium, strata of Devonian, Silurian, Ordovician, and Cambrian(?) age are exposed; these are succeeded on the flanks by strata of Pennsylvanian and Mississippian age. All of these strata have been folded and faulted to the accompaniment of widespread, weak to low-grade, regional metamorphism. This metamorphism was essentially dynamic and controlled by orogenic movements and differential stresses acting at low to moderate temperatures. Most of the larger faults are thrusts and high-angle reverse faults, but there are many normal faults of relatively limited extent and innumerable joints and fissures. Individual folds range from simple and open, through tightly compressed, to compound fan folds, both normal and inverted. The large composite folds such as the anticlinoria and synclinoria extend for considerable distances, but the individual folds overlap lengthwise, are narrow, and can be traced only a few miles along their axes (Miser and Purdue, 1929). Topography is controlled by the individual folds, as the outcropping edges of the resistant strata upturned on the folds form the ridges and the softer intervening strata underlie the valleys. The folds in Arkansas are overturned in large areas, but the folds in most of the Oklahoma area are open, though asymmetric (Miser, 1929). The Arkansas novaculite and the Jackfork sandstone are competent units and are bent into closely compressed folds through much of the central anticlinorium; closely compressed anticlines broken by faults are especially abundant in parts of the region that contain the Arkansas novaculite.

In the Choctaw anticlinorium, Honess found many anticlines and synclines in the Upper Ordovician, Silurian, and Devonian rocks, most of them unusually narrow and tightly compressed. Not all of these folds extend into the Bigfork chert, and the Cambrian(?) and Lower Ordovician strata in the central core of the anticlinorium generally do not reflect the folds of the younger surrounding rocks. Honess (1923, p. 216) stated that the rocks of the core area do not seem to have been deformed so much from lateral compression as from an overriding by the superjacent formations. "Normal" faults are especially abundant in this core area compared to other parts of the Ouachita Mountains. Structure sections show that these faults are on the broken north flanks of anticlines which are overturned southward, and these "normal" faults may have originated as high-angle faults with subsequent rotation of both faults and anticlines (P. B. King, personal communication, 1959). Miser (1929, 1959) interpreted the core area to be a window through the overthrust sheet of the Boktukola fault, which lies north and northwest of the core area, but Miser's interpretation has been questioned by Pitt (1955), Tomlinson and Pitt (1955), and Misch and Oles (1957). These geologists believe that the core area is the crest of a practically unbroken anticlinorium with no major faults at its border.

Potato Hills Anticlinorium

One of the most complex areas in the Ouachita Mountains is the Potato Hills anticlinorium in Latimer and Pushmataha counties, Oklahoma. Strata exposed here range from the Womble shale (Ordovician) to the Stanley shale (Mississippian). Miser (1929, 1959) interpreted the area as a window, intricately folded and encircled by the trace of a thrust fault. He considered that the window fault is a southward continuation of the Windingstair fault, whose trace is about 3 miles north of the Potato Hills. The rock strata in the window and those of the thrust sheet are of the same character, except for a thin conglomerate in the Stanley in the window which is absent outside the Potato Hills. The anticlines in the window are more closely compressed than those outside the window (Miser, 1959).

Misch and Oles (1957), Tomlinson (1959), and others have questioned that the Potato Hills anticlinorium is a window. They regard the Potato Hills as an anticlinorium of closely spaced, steep, partly overturned folds. Some of the overturned anticlinal limbs have ruptured, and steep reverse faults have developed. These authors do not believe that there is a border fault which encircles the entire structure. The area has been mapped in detail by several competent field geologists, and while there is still no unanimity of opinion as to whether a window is present in the Potato Hills, no mapping has been published that is inconsistent with Miser's original interpretation.

A recent well drilled in the Potato Hills (Sinclair's Reneau No. 1, C SE NW of 32-3N-20E) encountered multiple reverse faulting and repetition of stratigraphic section, strongly supporting Miser's hypothesis.

Frontal Belt

Along most of the Ouachita structural belt the outer margin of sediments of Ouachita facies coincides closely with the outer boundary of faulted and folded structures resulting from the orogeny accompanying the formation of the Ouachita Mountains. However, in the frontal belt of the western part of the Ouachita Mountains in Oklahoma, the Ouachita structural belt extends beyond the outer margin of sediments of Ouachita facies and includes some foreland rocks and some rocks transitional between sediments of foreland and geosynclinal facies. Much of this area lies between the Choctaw and Ti Valley faults; the structure of this area has been mapped in great detail by Hendricks (1959) and Hendricks et al. (1947), and this discussion is largely abstracted from their publications.

The frontal belt of the Ouachita Mountains is characterized by numerous thrust faults with general northeasterly trends, small reverse faults, tear faults, small plunging anticlines and synclines, and a few large synclines. The reverse faults form a complex set roughly parallel with the Ouachita Mountains front, with a related set of cross faults. A foreshortening of the strata by northwestward movement along the thrust faults has brought close together the different stratigraphic sequences in the different structural blocks.

The major faults in the frontal zone are the Choctaw, Katy Club, Pine Mountain, Ti Valley, and Windingstair. Horizontal movement on some of these faults was probably miles or tens of miles; a minimum cumulative total northward movement in excess of 50 miles is suggested (Hendricks, 1959). Thus, strata exposed southeast of the Ti Valley fault were probably deposited many miles southeast of the beds exposed west of the Choctaw fault, although they now lie within 3½ miles of the Choctaw fault in the western part of the area. The gliding planes along which thrust movement took place were incompetent shale zones with the principal zones being the Womble shale, Springer formation, Caney shale, Stanley shale, and Johns Valley shale.

Between the central anticlinorium and the frontal belt, southeast of the Windingstair fault and north of the Boktukola fault, are large synclines separated by thrust faults and broken by small reverse faults, normal faults, and tear faults. Many small plunging anticlines and synclines occur on the flanks of the large synclines and adjacent to thrust faults (Hendricks et al., 1947).

In conclusion, as pointed out by Hendricks (1959), the basic answer as to the nature of the forces which deformed the Ouachita geosyncline and produced the Ouachita Mountains system must be searched for beneath the coastal plain deposits which overlap the southern portion of the Ouachita Mountains.

The Marathon Area

PETER T. FLAWN

General Statement

The Marathon Basin of Brewster County, Texas, comprises about 1,200 square miles of low mountains, hills, and plains distinguished by sharp hogbacks and long sinuous ridges of steeply tilted Paleozoic strata; it is rimmed by escarpments of Cretaceous limestones to the east, south, and west and by escarpments of Permian and Cretaceous limestone to the north. The topographic basin is structurally an uplift or dome from which the cover of Cretaceous rocks has been removed. The climate of the region is semi-arid to arid, and vegetation is restricted for the most part to mesquite, low thorny bushes and shrubs, grasses, and varieties of cactus and yucca. Rock exposures are excellent.

The geology of the area has been described by Hill (1900), Udden (1907a), Baker and Bowman (1917), P. B. King (1931, 1937), Eifler (1943), Graves (1954), J. L. Wilson (1954a, 1954b), Fan and Shaw (1956), Berry and Nielsen (1958), and Berry (1958). King's report (1937) is a standard reference and presents a detailed analysis of stratigraphy and structure. The present report is concerned with larger features of sedimentation, orogeny, and regional correlation and draws freely on the basic work of others. Except for some brief studies of the Haymond boulder bed, no field studies were made in the Marathon area in connection with this project.

About 21,000 feet of Paleozoic rocks are exposed in the Marathon area. The Cambrian, Ordovician, and Devonian-Mississippian strata total 2,500 feet, Mississippian-Pennsylvanian rocks are 12,000 feet thick, and there are 6,500 feet of Permian beds (P. B. King, 1937, p. 19). Recent subsurface information indicates that Lower Permian Wolfcamp rocks thicken rapidly in the Val Verde basin north of the Marathon area and include clastic rocks older than those exposed in the type Wolfcamp section (Hall, 1956; Frenzel, 1957, pp. 2–3).

No attempt is made here to define or describe individual formations in detail; the stratigraphic sequence shown in Table 3 was compiled from P. B. King (1937), J. L. Wilson (1954a, 1954b), Fan and Shaw (1956), and Berry (1958). The stratigraphic synopses in the following section are based on P. B. King (1937) unless otherwise acknowledged.

CAMBRIAN, ORDOVICIAN, AND DEVONIAN STRATIGRAPHY

Stratigraphic Synopses

The oldest exposed formation in the Marathon area is the Upper Cambrian and Tremadocian Dagger Flat formation. The lower Buttrill Ranch member, the base of which is not exposed, consists of several hundred feet of unfossiliferous medium- to coarse-grained locally feldspathic micaceous sandstone; it is overlain by the 500-foot thick, locally fossiliferous Roberts Ranch member composed of dark shale, thin-bedded calcareous micaceous sandstone, and dark clastic sandy limestone (J. L. Wilson, 1954a, p. 2465). There is no apparent break between the Upper Cambrian Dagger Flat sandstone and the overlying Lower Ordovician Marathon limestone. The Marathon is composed of dark flaggy limestone, dark shale, and minor sandstone layers; the lower 250 feet contains abundant beds of intraformational pebble conglomerate commonly associated with coarse arkosic detritus toward the base of the unit. The middle member of the Marathon formation is named the Monument Spring dolomite. This unit is composed of massive mottled dolomitic limestone containing a foreland carbonate realm fauna ("El Paso"); it attains a maximum thickness of 90 feet and thins southeastward. The maximum thickness of the Marathon is approximately 1,000 feet, decreasing to 350 feet in its southeasternmost exposure (P. B. King, 1937, p. 26). J. L. Wilson (personal communication, 1957) suggested that this thinning is only apparent and probably results from faulting or squeezing in the southeast limb of the Dagger Flat anticlinorium; he pointed out that in the Solitario the Marathon formation is probably more than 1,000 feet thick. In the Javelina Canyon section the Marathon is intruded by a pre-Cretaceous gabbro sill (J. L. Wilson, 1954a, p. 2465). The Marathon limestone is overlain by 25 to 100 feet of greenish shale—the Alsate—which includes thin limestone beds in its southern exposures. Middle Ordovician rocks are represented by the Fort Peña formation, 125 to 200 feet of thick-bedded locally sandy limestone and bedded bluish to purplish chert with basal conglomerate beds, and the Woods Hollow shale, 180 to 500 feet of greenish clay shale and interbedded argillaceous calcareous sandstone, slabby sandy limestone, and limestone conglomerate. P. B. King (1937, p. 32) believed that the basal conglomerates of the Fort Peña rest unconformably on the Alsate shale, but J. L. Wilson (personal communication, 1957) interpreted the contact as transitional, and Berry (personal communication, 1957) reported that the graptolite faunas of the Alsate and Fort Peña are so closely related that the two units are probably not separated by a major time gap. There is a conformable gradation upward from the Fort Peña to the Woods Hollow. A distinctive feature of the Woods Hollow is the presence in some of the more southwesterly outcrops of sporadic fossiliferous limestone boulders of Early Ordovician and Late Cambrian age; these have been the object of a special study by J. L. Wilson who found (1954b, p. 250) a mixture of both the nearby North American fauna and an Atlantic province fauna. The prominent Upper Ordovician formation of the Marathon area is the Maravillas chert, a unit of interbedded limestone and black bedded chert 100 to 200 feet thick in the northwestern part of the Marathon Basin and thickening to 400 feet southward; in the northwest there is a thick coarse basal conglomerate made up of fragments from older rocks in the region and possibly including some material of foreland facies (J. L. Wilson, 1954a, p. 2469); southward, bedded black chert is more abundant and limestone beds decrease. The transition from Woods Hollow shale to Maravillas chert is sharp and distinct, and the presence of basal conglomerate in some areas indicates local uplift. P. B. King (1937, p. 36) pointed out that there is no truncation or thinning of the Woods Hollow and suggested that most of the discordance between the two units has been caused by later tectonic movements. J. L. Wilson (1954a) found a thin siliceous and gypsiferous shale between the Maravillas and the Caballos southeast of the Marathon area which he named the Persimmon Gap shale. The unit ranges from 5 to 40 feet in thickness and according to Wilson is of Upper Ordovician age; Berry and Nielsen (1958) from regional considerations concluded that this unit is Devonian, probably the middle shaly part of the Caballos which has overlapped the lower part of the novaculite to rest directly on the Maravillas. The Devonian system is represented by the most conspicuous ridge-making unit of the Marathon area—the Caballos novaculite. This siliceous unit ranges from 200 feet thick in the northwestern part of the area to 600 feet thick at the southern limit of its exposure and is mostly bedded chert, siliceous shale, and novaculite; bedded chert and minor limestone are more common to the northwest. The formation is divisible into a number of well-defined, widespread members (P. B. King, 1937, pp. 47–48). The lower Caballos is of restricted extent compared to the higher members (Berry and Nielsen, 1958).[8] The Caballos strongly resembles in lithology and stratigraphic position the Arkansas novaculite of the Ouachita Mountains which, on the basis of conodonts, has been classified as Devonian and Mississippian in age (Hass, 1951, 1956); probably the Caballos also includes beds of Kinderhook and possibly Osage age.

Stratigraphic Analysis

The early Paleozoic sequence in the Marathon area consists of medium- to coarse-grained sandstones overlain by relatively thick beds of shale, muddy limestone, and chert with subordinate sandstone and conglomerate. Total thickness of this sequence is unknown. P. B. King (1937, p. 22) interpreted the structural features of the exposed Cambrian and Ordovician rocks as indicating an underlying mass of incompetent strata of considerable thickness. In 1957, Fred Turner, Jr., No. 1 D. S. C. Coombs et al. (p. 234) was spudded in Dagger Flat sandstone near the base of the exposed early Paleozoic sequence and penetrated nearly 14,000 feet of sandstone and shale without encountering basement rocks. Although this sequence is probably steeply dipping and repeated by faulting, there is clearly a great thickness of Paleozoic strata beneath the oldest exposed rocks.

The predominant Ordovician shales of the Marathon Basin give way southward to more sandy rocks in the Solitario and Dove Mountain areas; southward, the Dagger Flat type of sandstone rises in the section and replaces the lower part of the Marathon formation, massive quartzite beds appear below the Fort Peña (probably at the Alsate position), black chert increases at the expense of limestone in the Maravillas, and a shale occurs between the Maravillas and Caballos (J. L. Wilson, 1954a, p. 2471). Rocks of the Marathon region are transitional between the chiefly carbonate foreland shelf and basin facies to the north and northwest and the more clastic and more typically Ouachita facies of the Solitario and Dove Mountain areas to the south; there were periodic transgressions of shelf facies rocks southward (Monument Spring dolomite member of the Marathon limestone) and clastic facies northward (arkosic detritus in the lower part of the Marathon limestone). The source of the clastic sediments lay to the south, and in early Paleozoic time the Marathon region was an area of mud deposition, alternating between fine clastics and limestone. In the over-all picture, the Marathon rocks are of Ouachita facies. Rocks in the southern Solitario and Dove Mountain exposures are similar to early Paleozoic rocks exposed in McCurtain County, Oklahoma. The Woods Hollow exotic boulders have been interpreted by J. L. Wilson (1954b, p. 258) as slumped from a Middle Ordovician fault scarp north and west of the belt, an interpretation similar to that given by P. B. King (1937, p. 47). The conglomerate at the base of the Maravillas indicates uplift and erosion, at least locally, between Woods Hollow and Maravillas deposition (King, 1937, p. 36). These stratigraphic features are proof of Ordovician structural movements and suggest an early history of at least sporadic mobility in this part of the Ouachita structural belt.

There is no question but what there are differences between the Ordovician faunas of the northwestern shelf and the faunas of the rocks of the Marathon area, but more study is needed to determine the degree of the difference. King (1937, p. 25) said:

> The faunas [of the Marathon Ordovician section] are mostly of a specialized facies, with plentiful floating and attached graptolites, associated with linguloid and oboloid brachiopods, pteropods, and trilobites. A very different contemporaneous facies is found in exposures 100 miles to the northwest, where the rocks are nearly all dolomitic limestones . . . and contain faunas characterized by orthoid brachiopods, cephalopods, corals, and sponges. The differences between the two sections are, however, more apparent than real, for several fossils and a few faunal groups

[8] Berry and Nielsen (1958) have proposed that the name Caballos novaculite be restricted to the lower unit and the name Santiago formation be applied to the upper unit.

are found in both regions. There is no suggestion that the strata were deposited in separate seaways. It is probable that the more or less clastic Ordovician strata at Marathon were deposited on or near muddy shores, in agitated water, and that the limestones with the gastropod-cephalopod assemblages were deposited farther from shore, in clean and quiet water.

J. L. Wilson (1954a, p. 2474) emphasized the faunal difference:

. . . a pronounced biofacies change is consistently present between Ordovician faunas of the Ouachita-Marathon belt and those of the West Texas and Arbuckle areas. The change is from a graptolite, corneous brachiopod and/or pelagic mud-dwelling trilobite biofacies to the more common Ordovician benthonic association of corals, bryozoans, sponges, calcareous brachiopods and nektobenthonic trilobites. The biofacies separation is not complete and enough genera are common to both to permit reasonable correlation, but the general aspect of the two faunas is very different. What little descriptive paleontology has been done in both areas indicates different early Paleozoic biofacies between the Ouachita-Marathon trough and the basinal areas lying northwest of it.

The presence of common genera in the Marathon area and the northwestern shelf and foreland basins and the evidence of southward transgressions of carbonate facies show that there was no real physical barrier between the two areas. The difference was rather one of tectonic setting with the Marathon area on the foreland side of an embryonic mobile belt which began to show signs of activity in Ordovician time. The present juxtaposition of the two facies is the result of late Paleozoic dislocation and northwestward thrust faulting. The dark graptolite shale and chert sequence is not a common near-shore facies (as suggested by J. M. Barton, 1945, p. 1338) but represents trough deposition in an area of low or restricted sediment supply with volcanic activity furnishing the silica in the form of ash.

Stratigraphic Synopses

The Tesnus formation overlies the Caballos with pronounced unconformity; it initiated a completely different type of sedimentation in the Marathon area. The break between the Caballos, which probably includes lowermost Mississippian, and the Tesnus, the lower part of which is probably of Mississippian age, occurs somewhere within the Mississippian period and is notable not so much because of the length of time it represents but because of the tectonic events which must have occurred during it. The Tesnus formation may include Lower Pennsylvanian rocks of Springeran age (Moore and Thompson, 1949, pp. 288–289). The Tesnus is a great southward-thickening wedge of clastic rocks with a thin basal conglomerate and ranges from 300 feet thick in the northwest to 6,500 feet thick in the southeast. P. B. King (1937, p. 55) described the Tesnus as a mass of interbedded sandstone and shale changing in facies from predominantly black shale in the northwest to mostly sandstone in the southeast where some arkose and light-colored quartzite layers are present. Fan and Shaw (1956) divided the Tesnus into a lower marine unit consisting chiefly of siliceous shales and massive low-rank graywackes[9] and an upper shale unit (which they interpret on rather tenuous evidence as a nonmarine shale derived from the weathering of pyroclastic rocks). P. B. King (personal communication, 1957) remarked that the basal shale in the southeast part of the area is a mappable unit nearly 1,000 feet thick and deserves member rank equally with the upper member of Fan and Shaw. The Tesnus has been called a flysch deposit (Van de Gracht, 1931a, p. 1031; P. B. King, 1937, p. 87). Lying conformably on the Tesnus is a gray, granular, locally bituminous, sandy limestone, of Morrowan age—the Dimple limestone. It is shaly toward the base and grades downward into the Tesnus and upward into the overlying Haymond formation. The Dimple is about 1,000 feet thick in the eastern part of the Marathon Basin and thins south and west. The Haymond formation (Atokan) consists of about 3,000 feet of shale and sandstone in a regular alternation of thin beds. In the upper part of the unit there are thick beds of arkose and boulder-bearing mudstone containing remarkable exotic boulders of older Paleozoic formations and round pebbles and cobbles of igneous and metamorphic rocks from an unknown source. The Haymond boulder beds have been fully discussed in the literature (P. B. King, Baker, and Sellards, 1931; Sellards, 1931a; P. B. King, 1932, 1937, 1958; Baker, 1932; Carney, 1935; Flawn, 1956, 1958; Hall, 1957). Gaptank sandstones and shales with interbedded conglomerates and limestones conformably overlie the rocks of the Haymond formation. The formation attains a thickness of 1,800 feet and spans Des Moines, Missouri, and Virgil time (Moore and Thompson, 1949, pp. 288–289). The conglomerates, mostly occurring near the middle of the unit, contain fragments of older Paleozoic units, which occur to the south and many thousands of feet lower in the stratigraphic sequence, but no foreign fragments of igneous or metamorphic origin. The Gaptank is probably a molasse facies (Van der Gracht, 1931a, p. 1033; P. B. King, 1951, p. 135). Marked angular unconformity separates the Gaptank from the basal Wolfcamp conglomerates in some areas, particularly in the southwestern Glass Mountains; to the northeast there is near concordance between the two units. Higher in the sequence, Leonard (Hess) beds rest unconformably on Wolfcamp strata, indicating post-orogenic tilting later in Permian time. The Permian rocks exposed in the Glass Mountains comprise about 5,000 to 7,000

[9] From the percental compositions shown by Fan and Shaw (1956), it appears that these Tesnus rocks might better be called subgraywackes or argillaceous sandstones.

feet of marine strata, mostly carbonates. Within recent years, however, drilling has shown the presence of a considerable thickness (possibly as much as 10,000 feet) of clastic Wolfcamp rocks—sandstones and siltstones of "geosynclinal facies"—northeast and east of the Marathon region in Terrell and Pecos counties (Hall, 1956; Frenzel, 1957; Galley, 1957; Addison Young, 1960); this clastic sequence is older than the Wolfcamp section lying on Gaptank exposed in the Glass Mountains.

Stratigraphic Analysis

The change within Mississippian time from slow accumulation of siliceous material in the Caballos to the rapid dumping of the clastic debris in the Tesnus demonstrates a convulsive movement of the Ouachita mobile belt toward the foreland. The southeastern part of the belt emerged and began to shed sediments into a downwarped trough in an area which through early and middle Paleozoic had been far north of the active part of the belt—the axis of major deposition shifted toward the foreland. The rapid thickening of the Tesnus wedge to the south and the presence of fragments of igneous and metamorphic rocks within sandstones and arkoses of both Tesnus and Haymond formations prove the proximity of this new source area. The Tesnus and Haymond are grouped by P. B. King (1937, p. 119) as flysch—apparently the Dimple limestone represents a break in the flysch cycle. These rocks were probably deposited in deep water in troughs between tectonic ridges. Near the Haymond-Gaptank boundary, water-rounded conglomerates and abundant shallow-water marine invertebrates mark a change in sedimentation and reflect a change in tectonic setting. Molasse facies Gaptank sediments were derived from the compressed, deformed, and uplifted earlier Paleozoic rocks of the foldbelt itself. Boulder beds in the upper part of the Haymond are interpreted as one-time submarine mudflows which carried blocks from locally uplifted structures into a rapidly subsiding trough (P. B. King, 1958, p. 1734). Middle Gaptank conglomerates contain no exotic material and are made up of fragments of older Paleozoic rocks, chiefly Maravillas, Caballos, and Dimple; they thin northwestward away from the deformed area. Van der Gracht (1931a, pp. 1034–1035) emphasized the tectonic significance of the disappearance of igneous and metamorphic sedimentary material in the upper Haymond and Gaptank strata, which clearly indicates a foundering or near sea-level reduction of the welt which supplied Tesnus and early Haymond sediments.

At the beginning of Wolfcamp time the axis of maximum sedimentation was again shifted northward, and a thick section of Wolfcamp clastics was dumped into the Val Verde basin area in northern Brewster, Terrell, and Pecos counties; probably these sediments were derived from still active folds and rising thrust blocks in the Marathon belt. Adams and Frenzel et al. (1952, p. 26) proposed the hypothesis that Wolfcamp beds have been thrust faulted in the area west of the town of Marathon, basing their idea on presence of Wolfcamp fusulinids in beds previously mapped as Gaptank. Later, Frenzel (1957, pp. 2–3) cited the section penetrated in the Woods Oil and Gas Company No. 1–47 Mary Decie et al., Brewster County, wherein Wolfcamp strata were encountered beneath a klippe of the Dugout Creek overthrust, as additional evidence that thrust faulting in the Marathon area continued into Wolfcamp time. The unconformity at the base of the Hess conglomerate records emergence, uplift, and tilting, probably resulting from post-orogenic movements of the deformed Ouachita belt. Late Wolfcamp and succeeding Permian deposition was in a marine-carbonate environment.

TABLE 3. *Paleozoic formations of the Marathon region.*[1]

AGE	FORMATION	THICKNESS (*feet*)	LITHOLOGY
Lower Permian	Wolfcamp formation	500	Coarse massive conglomerate, shale, limestone
	unconformity		
Middle and Upper Pennsylvanian	Gaptank formation	1,800	Shale, sandstone, conglomerate, fossiliferous limestone
Middle Pennsylvanian (Atokan)	Haymond formation	3,000	Sandstone, shale, boulder-bearing mudstone
Lower Pennsylvanian (Morrowan)	Dimple limestone	300–1,000 (thins southward)	Gray cherty limestone, shale, chert (more shale to east)
Lower Pennsylvanian (Springeran) and Mississippian	Tesnus formation: Upper Tesnus	100–800 (thickens southwestward)	Gray shale, black chert
	Tesnus formation: Middle Tesnus	200–6,000 (thickens southwestward)	Siliceous shale, sandstone (changes to massive sandstone southwestward)
	Tesnus formation: Lower Tesnus	up to 1,000 (southeast only)	Hard green shale
	unconformity		
Mississippian and Devonian	Caballos novaculite	250–600 (thickens southward)	Massive white novaculite, bedded varicolored chert
	unconformity		
Upper Ordovician	Persimmon Gap shale[2]	5–40 (thickens southward)	Pinkish-brown siliceous shale
	Maravillas chert	100–500	Bedded black chert, dark limestone
Middle Ordovician	Woods Hollow shale	180–500	Shale, thin flaggy limestone, sandstone
	Fort Peña formation	200	Massive limestone, bedded chert
Lower Ordovician	Alsate shale	25–100	Hard green shale, thin limestone beds
	Marathon limestone: Upper member	350–1,000 (thins southward(?); see p. 51)	Shale, flaggy limestone
	Marathon limestone: Monument Spring dolomite member		Mottled dolomitic limestone
	Marathon limestone: Lower member		Shale, flaggy limestone, pebble conglomerate
Upper Cambrian	Dagger Flat sandstone: Roberts Ranch member	500	Shale, sandy limestone, calcareous micaceous sandstone
	Dagger Flat sandstone: Buttrill Ranch member	300–900	Micaceous sandstone, shale

[1] Compiled from P. B. King (1937), J. L. Wilson (1954a), Fan and Shaw (1956), Berry and Nielsen (1958), and Moore and Thompson (1949).
[2] J. L. Wilson (1954a) classified this formation as Upper Ordovician; Berry and Nielsen (1958) considered it as part of the Caballos (Devonian).

DEFORMATION OF THE OUACHITA STRUCTURAL BELT IN THE MARATHON AREA

A complete description and analysis of the structures of the Marathon Basin are given by P. B. King (1937). The Paleozoic rocks have been thrown into a series of northeast-trending folds by late Paleozoic compressional deformation; the fold axes are commonly arcuate in plan with a slight northwest convexity. Thrust faults, overthrust faults, and tear faults are common. Two major anticlinoria—the Marathon anticlinorium and the Dagger Flat anticlinorium—are separated by the Peña Colorada synclinorium. The Dugout Creek overthrust, most northwestward of the important overthrusts, has a minimum displacement of 6 miles.

The structures are similar to those found in folded mountain chains the world over, and many geologists have referred to them as "Appalachian type." As in other orogenic belts, the compressive orogenic phase was followed later by broad, epeirogenic uplift in Mesozoic time.

A number of lines of evidence, perhaps more properly called reasoning, indicate that the Marathon Basin exposes a structural salient of the Paleozoic orogenic belt: (1) In the broad, regional picture the Marathon segment is a strong northwestward culmination which marks a change in trend of the orogenic belt as defined by drilling to the east and west (Pl. 2); (2) the pattern of the structures exposed within the basin, mainly the northwestward convexity of the axes in plan, suggests a salient; (3) strong northwestward overthrusting has transported the Marathon facies rocks toward the foreland for at least 6 miles along the Dugout Creek overthrust, and this break might border the entire northwest margin of the belt; major displacement is also indicated along the Hells Half Acre overthrust, and a minimum of 15 miles of crustal shortening has been calculated by P. B. King (1937, p. 131). Compared to the Ouachita Mountains, the folds are small in amplitude. King (1937, p. 134) explained this in terms of competence of beds and thickness of cover, but the over-all limitations of the size of the salient may have affected the magnitude of the folds within the culminating segment.

The question arises as to whether or not the entire Marathon segment is an allochthonous plate that has been moved out over the foreland and, if so, how far has it moved? In the writer's opinion the Marathon rocks have not moved as a unit along one great decollément surface, but the cumulative effect of "geosynclinal cannibalism" and overthrusting has been to effect a considerable northward or northwestward transport of Marathon rocks. Both Miser (1931, p. 1083) and P. B. King (1937, p. 137) have suggested, on the basis of rock facies, that the edge of the Marathon segment of the Ouachita geosyncline lay near the present northwest margin of the Basin, and King (1937, p. 137) has pointed out that the Dugout Creek overthrust might well be the marginal overthrust of the belt. Probably the margin of the *late* Paleozoic geosyncline did approximate the present margin of the belt, at least during the Pennsylvanian (figs. 2, 3, in pocket). The margin of the Early Permian downwarp was farther to the northeast, and the early and middle Paleozoic trough was farther southeast. The key to the problem lies in interpretation of the section in a recent well (Woods Oil and Gas Company No. 1-47 Mary Decie et al.; p. 237) which permits a check on the position of Ordovician foreland facies rocks.

According to Raymond Woods (personal communication, 1954, 1957), this well (*see* Pl. 2 for location) was spudded in a klippe of lower Paleozoic Ouachita facies rocks including Caballos novaculite, cut the Dugout Creek overthrust and several other thrusts in the upper section, and penetrated several hundred feet into the Ellenburger to a total depth of 9,741 feet. Hull (1957b, p. 96) reported that the top of the Wolfcamp was encountered at 165 feet below the Dugout Creek overthrust and the Wolfcamp section extended downward to 6,820 feet where Strawn rocks were penetrated (nothing was said in Hull's report about the lower section). About 8 miles southeast of the No. 1-47 Decie and 3 miles southeast of the outcrop of the trace of the Dugout Creek overthrust, Gulf Oil Corporation No. 1 D. S. C. Coombs was spudded in Woods Hollow shale and penetrated a lower Paleozoic Ouachita facies sequence including Dagger Flat sandstone (trilobites of Marathon age were found at 4,050 feet). Within the 5,840 to 6,100-foot interval the well passed through a thrust fault into fusulinid-bearing Pennsylvanian rocks (p. 234). As a matter for speculation, if the thrust cut in the No. 1 Coombs is the down-dip extension of the Dugout Creek overthrust, the fault plane has an apparent dip of about 20 degrees to the southeast in this area.

The Ellenburger rocks of foreland facies found in the No. 1-47 Decie indicate that: (1) through a process of "geosynclinal cannibalism" and successive northward development of foredeep troughs, the mobile belt had by Wolfcamp time advanced to a point where the axis of early Permian downwarp was in an area that had been a foreland carbonate basin in Ordovician time, and (2) during early Wolfcamp time overthrusting along the Dugout Creek fault and other unnamed subsurface breaks transported early and middle Paleozoic rocks of Marathon facies to a position over and many thousands of feet higher than their foreland equivalents. It seems clear that early and middle Paleozoic rocks of Marathon facies, ranging from the Dagger Flat through the Caballos, have been tectonically displaced a considerable distance from their original site of deposition in a series of strong compressional orogenic pulsations, the first of which is recorded in the Haymond boulder beds and the last of which is represented by Caballos resting in fault contact on Wolfcamp beds.

The Marathon salient is the result of the shape of the Precambrian craton against which the Ouachita belt was deformed. Eastward the belt was crushed against and around the broad bulge of the Llano uplift, the southeastern nose of the Texas craton; west of the Marathon area the course of the Ouachita chains was deflected southward by a late Precambrian addition to the older craton, the deformed rocks of the Van Horn mobile belt (Flawn, 1956, p. 70). The Van Horn mobile belt was welded to the craton by late Precambrian orogeny and intrusion and, as the Paleozoic Diablo Platform, formed a stable southern foreland for the Ouachita system (p. 166). The "bay" thus created in the Ouachita system's foreland served to channel the late Paleozoic orogenic forces in this area, and a structural salient was the result.

The first indication of tectonic activity in the Marathon segment of the Ouachita belt is recorded by a coarse arenaceous facies in the Early Ordovician beds of the southeasternmost exposures of the belt, by the exotic boulders of the Middle Ordovician Woods Hollow shale, and by the Upper Ordovician basal Maravillas conglomerates. P. B. King (1937, p. 42) noted "... evidence of marked uplift and diastrophism in the region near the Middle and Upper Ordovician boundary," and J. L. Wilson (1954a, p. 2455) said: "The Ordovician section of the interior (southeasternmost) folds of the Ouachita-Marathon system suggests that orogenic activity occurred in the system in Ordovician time. . . ." In all probability the stratigraphic evidence of this disturbance visible in exposures today is only a faint northwestern reflection of an extensive Ordovician orogeny that took place to the southeast of the present-day exposures and whose conglomerates and intrusions are now concealed beneath a great thickness of younger sedimentary rocks.

The hiatus and unconformity between the Caballos novaculite and the Tesnus, and the thin basal conglomerate of the Tesnus are evidence of Mississippian uplift, probably in the early or middle part of the period. The advent of Tesnus sedimentation marks the beginning of the late Paleozoic orogeny, and, with the exception of the quiescent period of Dimple limestone deposition, the succeeding stratigraphic column, representing almost continuous sedimentation, carries the evidence of a series of orogenic pulses in flysch-molasse deposition and conglomerate beds. P. B. King (1937, p. 119) has referred to this diastrophism as the "Marathon orogenic epoch" and recognized six episodes from the beginning of Tesnus time through Wolfcamp time, namely, (1) strong uplift of the hinterland, (2) overthrusting in the southeastern part of the area, (3) beginning of folding, including folding of the first overthrusts, (4) strong folding and overthrusting, (5) warping followed by erosion, and (6) tilting and folding. Recent subsurface evidence that lower Wolfcamp beds were involved in late thrusting (Woods Oil and Gas Company No. 1-47 Mary Decie et al., p. 237) may call for a modification of King's episode No. 6 to include thrust faulting in early Wolfcamp time.

The stratigraphic record shows that orogenic activity in the Marathon segment of the Ouachita structural belt began with the Tesnus and ended during Wolfcamp time. Movements were *intermittent* throughout Late Mississippian, Pennsylvanian, and Early Permian. Hall (1956) deserves credit for recognizing the importance of Wolfcamp orogenic movements, but the writer does not concur with him in making a sharp separation between a Lower Pennsylvanian orogeny dated by the Tesnus and an Early Permian (Wolfcamp) orogeny dated by the lower clastic Wolfcamp section. The Dimple limestone does record a period of quiescence between the two orogenic facies sedimentary sections, at least in the area of its occurrence, but the flysch character of the Haymond, the boulder beds in the upper Haymond, and the Gaptank conglomerates record continuing tectonism in the Late Pennsylvanian. The Tesnus clastic wedge and the Wolfcamp clastic wedge which Hall cites as evidence of two separate orogenies (separated by epeirogenic movements) merely record the normal progress of geosynclinal deformation and shifting of the axis of maximum deposition toward the foreland.

The significance of the rocks and structures of the Marathon Basin was recognized in 1931 by Van der Gracht; he did not have the benefit of the detailed stratigraphic work and well data available today, and in the writer's opinion, the following quotation (1931a, p. 1042) testifies to his remarkable geologic perception.

> The importance of the Marathon Mountains, as part of a major structural feature, is indicated by many signs. The wide development of an early Pennsylvanian foredeep, and, farther out, of an early Permian foredeep, and the orogenic facies of the deposits filling these troughs; the asymmetric profile of these foredeeps, and the fact that the depression moved progressively outward from the mountain front in later Pennsylvanian and Permian times; the very great intensity and duration of the Arbuckle phase [name given to an orogenic phase of middle Cisco time]; and, finally, the important flat overthrusting of the Dugout Creek and Solitario nappes—these all indicate a major orogeny. It is the history of a large and important mountain chain.

Other Exposures of the Ouachita Belt

PETER T. FLAWN

CENTRAL TEXAS

In the spring of 1948, Barnes discovered a sequence of steeply dipping dark shales and interbedded sandstones of Carboniferous age along the Colorado River in Travis and Burnet counties (Barnes, 1948). These rocks overlie Marble Falls limestone and were identified as Smithwick (Morrow? Atoka?); because of the dark color of the rocks, their general lithology, and their steep dips, Barnes suggested that they might be within the Ouachita structural belt. The Marble Falls formation in the area strikes east of north and dips eastward with progressive inclination ranging from 10 to 15 degrees in the western part of the exposure to 70 degrees in the eastern outcrops; sandstone beds in the overlying shale sequence strike northeast and show dips up to 70 degrees to the southeast. The exposures occur in the bottom of the channel of Lake Travis in the Turkey Bend area and in the bottom of Cypress Creek; they are visible only at times of low water. Because of the limited exposures it could not be determined whether or not local faulting was responsible for the structure.

Thin-section examination of sandstone from within the dark shale sequence indicates that these rocks are not Ouachita facies as the term is used in this paper (p. 13); the rocks are fine-grained, subangular to subround, fairly well-sorted, cherty quartz sandstones of foreland type. Their foreland character is confirmed by the normal carbonate facies of the underlying Marble Falls; in the Ouachita sequence the Marble Falls carbonate unit is not present and probably it grades into a clastic unit east of the Llano uplift. But although the rocks are not of Ouachita facies, their structure suggests that they are within the northwestern margin of the belt. The Turkey Bend exposures are on the southeast side of the Llano uplift and deformed Ouachita facies rocks occur only 5 miles to the southeast. This is the area of maximum deformation of the folded belt where the orogenic forces were directed against the unyielding buttress of the Llano uplift; in this locus of maximum deformation it is reasonable to suppose that the foreland facies rocks mantling the southeast side of the uplift were caught up in the late Paleozoic folding and that, in this area, deformed foreland facies rocks occur within the frontal structures of the Ouachita belt.

SOLITARIO AREA

General Statement

The Solitario is a nearly circular uplift, about 9 miles in diameter in southwestern Trans-Pecos Texas wherein northeast-southwest-trending Paleozoic rocks are completely encircled by a high-standing rim of Cretaceous rocks; the Paleozoic exposures are about 35 miles southwest of the southwesternmost exposed Paleozoic rocks in the Marathon Basin. The geology of the Solitario area has been described by Udden (1907a), Powers (1921), Sellards, Adkins, and Arick (1931), Baker (1935), Lonsdale (1940), J. L. Wilson (1954a), and Herrin (1959). The following discussion is based largely on the work of Herrin (1959).

The Paleozoic sequence exposed in the Solitario resembles that of the Marathon area and the same stratigraphic terminology is applicable (Table 3). Recently, Berry (1960, p. 20) noted that in the Solitario and old Jones ranch areas a white to buff quartzose sandstone occurs between the Marathon and Fort Peña formations occupying the same position as the Alsate shale farther north; he proposed the name Rodriguez Tank sandstone for this unit. Cambrian and Lower to Middle Ordovician beds are mostly sandstone and shale; the shale is calcareous and the minor limestone beds in the sequence are nearly all sandy. The Upper Ordovician and the Devonian to Lower Mississippian rocks are bedded chert, novaculite, and minor limestone. Upper Mississippian and Pennsylvanian rocks are siliceous black shale and massive quartzite. The rocks have been thrown into sharp asymmetric folds overturned to the northwest; a low-angle thrust, the Solitario thrust, has transported younger rocks over older rocks and is exposed in the interior of the uplift as a result of later folding. Cambrian and Ordovician rocks are exposed in a window of the thrust sheet.

Stratigraphic Synopses

The base of the stratigraphic sequence is not exposed in the Solitario uplift. The oldest exposed unit is the Dagger Flat sandstone which consists of about 600 feet of drab sandstone and sandy shale; the sandstones in the lower part are poorly sorted and contain angular grains of quartz, feldspar, chert, shale, and mica; higher, the sandstones are more calcareous. The Marathon formation, 1,500 to 3,000 feet thick, rests conformably on Dagger Flat beds and is composed of dark siliceous shale, dark chert, poorly sorted sandstone, and sandy limestone with a few beds of slabby blue limestone; the formation thus contains much less carbonate than in the Marathon area. Alsate shale has not been recognized in the Solitario. The Fort Peña formation is of much the same character as in the Marathon Basin; it is massive sandstone and quartzite, sandy and siliceous limestone, chert, and calcareous shale about 400 feet thick. Between it and the Woods Hollow shale is a transitional unit about 50 feet thick wherein sandy limestone gives way to black shale with thin sandstone partings. The Woods Hollow is 400 feet of black fissile shale, light-colored thin fairly well-sorted sandstone beds, and a few thin beds of flaggy limestone. The Woods Hollow is overlain conformably, but with a sharp change in lithology, by the Maravillas chert, which is bedded black chert 200 feet thick containing sporadic lenses of brown limestone and chert pebble conglomerate.

The Maravillas is unconformably overlain by the Caballos formation, 280 feet of light-colored banded chert and novaculite with a red and green shale locally at the base.

The youngest Paleozoic unit in the Solitario area is the Tesnus formation of which about 4,600 feet is preserved; it is massive brown siltstone, very fine-grained sandstone, and dark green shale, variably siliceous, like the Tesnus of the Marathon Basin. The sandstone is a fine-grained, angular, poorly sorted, chloritic micaceous feldspathic rock containing fragments of chert, shale, and metamorphic rocks.

Tertiary igneous rocks, mostly rhyolite, occur as dikes, sills, and small stocks, and the extrusive Buck Hill series overlies the older rocks.

Stratigraphic and Structural Analysis

The Solitario uplift exposes the southwesternmost Paleozoic rocks of the Ouachita belt in the United States. Some units in the Solitario are nearly like those in the Marathon Basin but others differ in mineralogy and texture. Greatest differences are in the older Ordovician beds, such as the Marathon formation, which are more clastic and siliceous (J. L. Wilson, 1954a, pp. 2458, 2471; Herrin, 1959, p. 42). The Solitario may lie nearer to the axis of the Ordovician geosyncline than the Marathon area (Herrin, 1959, p. 47), although the source of sediment was still farther south or southeast. The Tesnus contains more rock fragments than in the Marathon Basin and perhaps, like the Marathon formation, was deposited nearer to the source than equivalent beds in the Marathon Basin.

Folding and thrust faulting in the Solitario is like that in the Marathon area and the Ouachita Mountains. Major structures strike northeast as in the Marathon Basin. The Solitario thrust is mappable for about 4 miles and has a displacement of about 4,000 feet (Herrin, 1959, p. 123). Presumably the Paleozoic rocks in the Solitario area were deformed at the same time as the rocks of the Marathon area. Although there may be local incipient to very weak alteration in rocks in this area, additional petrographic work will have to be done to demonstrate the distribution and degree of metamorphism. It is unlikely that these frontal zone rocks experienced regional low-grade metamorphism.

General Statement

Paleozoic rocks of Ouachita facies are exposed in the Persimmon Gap and Dog Canyon areas of Brewster County, Texas (Bone Spring quadrangle), about 10 miles south of the southernmost exposures of Paleozoic rocks in the Marathon Basin and about 40 miles east-northeast of the Solitario. These rocks have been described by Maxwell et al. (1949, pp. 27–28), J. L. Wilson (1954a), Lonsdale et al. (1955, pp. 54–59 and map), Hazzard, Maxwell, and Lonsdale (1958), Berry and Nielsen (1958), and Maxwell et al. (MS).

Strongly deformed Paleozoic rocks occur in a series of separate exposures in the Santiago Mountains in a northwest-southeast-trending belt about 6 miles long between Persimmon Gap on the northwest and the general area of Dog Canyon on the southeast. The area has been subjected to both Paleozoic and Cretaceous thrust faulting, and many of the exposed Paleozoic rocks are in thrust slices or parts of dislocated plates. The Paleozoic rocks include undifferentiated Ordovician rocks (probably Marathon and Alsate formations), Maravillas chert, Caballos novaculite (upper unit), and Tesnus formation.

Stratigraphic Synopses

According to Maxwell et al. (MS), the oldest Paleozoic unit in the Persimmon Gap–Dog Canyon area is probably a strongly deformed and crumpled mass of flaggy dark shale with minor thin limestone beds which has been thrust over the Georgetown formation and in turn has been overridden by strata of the Fredericksburg group. From their lithology, these rocks appear to be either Marathon or Alsate; thickness does not exceed 100 feet. A slice of Maravillas chert probably about 200 feet thick is exposed in the core of the Santiago Mountains structure resting on beds of the Tesnus formation; it consists of gray to black chert, gray, brown, orange, and pink shale (with graptolites in one shale bed), dark brown to black limestone, and thin chert-limestone pebble conglomerates; all these are extensively jointed and fractured. Several other smaller exposures of Maravillas chert ranging from 15 to 76 feet thick occur in the Persimmon Gap–Dog Canyon area. Near Persimmon Gap there is an exposure of all three subdivisions of the upper unit of the Caballos novaculite (Santiago formation of Berry and Nielsen, 1958). From the base upward they consist of 45 feet of reddish shale and chert, 30 feet of light gray to white novaculite, and 40 feet of interbedded dark chert and siliceous shale. These rocks lie unconformably on Maravillas beds and are overlain unconformably by the Tesnus formation. The major exposure of the Tesnus occurs in Persimmon Gap and consists of hard dark shale and dark fine-grained sandstone cut by veinlets of white quartz (Pl. 7, A). The base of the Tesnus is a thin conglomerate composed of dark chert and light-colored novaculite pebbles. The Tesnus in this area is thrust over Cretaceous rocks and overridden by Maravillas chert and has been extensively jointed and fractured. There are also other smaller exposures of Tesnus beds elsewhere. Maxwell et al. (MS) estimate that not more than 500 feet of Tesnus strata is exposed in the area.

Reconnaissance petrographic study of Tesnus sandstones from the Persimmon Gap area shows that the rocks are fine-grained, angular to round, poorly sorted, argillaceous-chloritic feldspathic quartz sandstone or arkose veined by calcite-hematite. Most of the quartz has strongly undulose extinction. The abundant feldspar is mostly plagioclase partly altered to calcite, but subordinate potassium feldspar is also present. Mica shreds, a few fragments of chert and phyllite-schist, and some carbonaceous debris were observed. The heavy mineral fraction includes large round to subhedral zircons, apatite, rutile, leucoxene, and tourmaline.

STRATIGRAPHIC AND STRUCTURAL ANALYSIS

The Paleozoic rocks of the Persimmon Gap–Dog Canyon area provide a glimpse of the southeasternmost exposures of unmetamorphosed rocks of the frontal zone of the Ouachita structural belt in Trans-Pecos Texas. Although the exposures are small and extensively deformed so that it is difficult to make detailed comparisons with the Marathon Basin sequence, certain broad conclusions can be drawn.

The most important is that the major formations of the Marathon Basin sequence persist southward for at least 10 miles without radical change. The rocks are more jointed and fractured than in the Marathon Basin, but this appears to result from involvment in Cretaceous deformation rather than an increase in severity of Paleozoic deformation south of the Marathon area. Veining does not seem more extensive than to the north. Because of the fragmentary sections, the only information available on thickness changes pertains to the Caballos novaculite, the upper part of which appears to thin southward (Berry and Nielsen, 1958). Not enough petrographic work has been done to determine whether or not the Tesnus sandstones are more arkosic in this area than to the north.

It is clear that the same type of Paleozoic deformation took place in this area as in the Marathon Basin to the north, and apparently there is no change in the trend of the Paleozoic axes; Paleozoic thrusting was from southeast to northwest (Hazzard, Maxwell, and Lonsdale, 1958). If the trend of the Paleozoic structures in the Persimmon Gap–Dog Canyon area is northeast-southwest and the axes are projected northeastward, they strike toward the Jones ranch area in the southeastern tip of the Marathon Basin where pre-Tesnus Ouachita facies rocks are exposed and have been encountered in wells (Pl. 2). Perhaps the Persimmon Gap–Dog Canyon and Jones ranch exposures are part of a third great anticlinal structure more or less parallel to the Dagger Flat and Marathon anticlinoria to the north (Pl. 2).

The Subsurface Ouachita Structural Belt in Texas and Southeast Oklahoma

PETER T. FLAWN

General Statement

In mapping subcrop geology, the procedure followed is very much like the one used to construct areal geologic maps of the bedrock where it is obscured by heavy soils, glacial deposits, or alluvial cover; the characteristics of the rocks penetrated in a number of wells are plotted on a base map and similar rocks are grouped to form map units. In the frontal zone of the subsurface Ouachita belt where the rocks are unmetamorphosed and can be correlated with formations in the Ouachita Mountains or Marathon region, the problem is one of establishing the course and structural attitude of as many units as well control permits. In attempting to map metamorphosed rocks in the interior part of the belt—rocks which do not appear to have outcropping equivalents—the distinction between rock units and belts of metamorphism is important. Rocks of different ages and character might appear to be similar where they have been overprinted, so to speak, with the same degree and kind of metamorphism. This problem manifests itself in the eastern and southern part of the Ouachita belt in central Texas where belts of differing degrees of metamorphism transect lithologic boundaries. In delimiting mappable *lithologic* units, the rocks are grouped by basic lithologic and mineralogic characters rather than by degree of reconstitution or similarity of metamorphic structures.

The following lithologic units are mapped on the subcrop of the Ouachita belt in Texas and southeast Oklahoma: (1) Cambrian(?) through Devonian (possibly including Lower Mississippian) rocks of Ouachita facies, pre-Stanley and pre-Tesnus beds; (2) Mississippian-Pennsylvanian rocks of Ouachita facies, including Atoka formation, Jackfork sandstone, Stanley shale, Tesnus formation, and Mississippian-Pennsylvanian rocks undivided; (3) dark fine-grained to coarse-grained clastic rocks of unknown age; and (4) phyllite, slate, metaquartzite, marble, and schist of unknown age.

CAMBRIAN(?)—LOWER MISSISSIPPIAN ROCKS OF OUACHITA FACIES

Lithologic Descriptions

The pre-Stanley (pre-Tesnus) sequence includes distinctive siliceous units; the major lithologic types are chert and siliceous shale, limestone and dolomite, shale, siltstone, and sandstone. The rocks are commonly veined by quartz, quartz-bitumen, and calcite or dolomite; in the siliceous rocks extensive vein networks are common; in some slightly metamorphosed shale-sandstone samples, reconstitution adjacent to veins is reflected by development of coarse chlorite-sericite (p. 118). In some areas these rocks are unmetamorphosed, in other areas they have been subjected to incipient to very weak metamorphism, and, locally, they are low-grade metamorphic rocks (pp. 121–124 and Pl. 2).[10] In the metamorphosed terranes the rocks are deformed and show foliation, slaty cleavage, and fracture cleavage.

In Lamar and Red River counties, Texas, pre-Stanley rocks are variably metamorphosed and are similar to pre-Stanley rocks exposed in the Ouachita Mountains in the Broken Bow–Benton anti-

[10] Throughout this report the terms incipient, very weak, weak, and low-grade metamorphism are defined within specific limits (Table 1).

clinorium (p. 25). Sericite and chlorite phyllite, slate, metaquartzite, metachert, and marble locally showing foliation, slaty cleavage, fracture cleavage, and convolution have been penetrated in this area. In Bentley, Shepherd, and Stevens No. 1 Southern Pine Lumber Company in Red River County, green hornblende occurs in metaquartzite, and the calcite marble in Johnston Petroleum Syndicate No. 1 Lady Alice in Red River County is graphitic dolomitic calcite marble (Pl. 8, D).

Chert-siliceous shale.—Ouachita facies cherts range from light-colored (tan, greenish) to dark (brown, black) microgranular to cryptocrystalline to chalcedonic chert, commonly dolomitic, argillaceous, pyritic, with abundant dark red-brown to black organic material in masses, streaks, or evenly distributed in such quantity as to render the rock nearly opaque (Pl. 5, B, C, D). The dark cherts commonly are spore- and/or radiolarian-bearing and/or spiculitic (Pl. 8, C). Siliceous shales are a transitional phase and except for their clay-mica content are similar to the cherts. These siliceous rocks are locally fractured, brecciated, or completely shattered. Incipient to very weak metamorphism is not visibly reflected in them—degree of metamorphism in these sequences is inferred from study of associated shale-sandstone.

Limestone-dolomite.—Where limestone and dolomite occur, they are always associated with dark chert and siliceous shale. They are fine-grained limestone, dolomitic limestone, and dolomite, commonly glauconitic, argillaceous, siliceous, pyritic, and slightly fossiliferous, and commonly containing dark organic matter. The fossil material is a fine debris composed mostly of spicules but also including small gastropods, commonly pyritized, and pelmatozoan fragments. These carbonate rocks grade into chert and siliceous shale, and transitional types are common. Except for local twinning, effects of incipient to very weak metamorphism are not evident, but higher metamorphism is recorded in some areas. One well in Red River County (Johnston Petroleum Syndicate No. 1 Lady Alice), located on the southwest extension of the Broken Bow–Benton anticlinorium (southwest of McCurtain County, Oklahoma), penetrated a sequence containing a graphitic quartzose dolomitic calcite marble. Stratigraphic relations in McCurtain County indicate an early Paleozoic age, so this marble is probably early Paleozoic; in Terrell County in west Texas, R. E. Freeman No. 1 Barksdale penetrated a sequence of very weakly metamorphosed dark fine-grained dolomitic spiculitic limestone and fine-grained dolomite that is probably correlative with the Marathon limestone in the Marathon region.

Shale.—Pre-Stanley shale (excluding siliceous shale) is of two main types: (1) dark gray-green shale, rarely brown or black, commonly containing rhombs or hour-glass porphyroblasts of "pleochroic" carbonate—probably dolomite or siderite, locally micaceous, chloritic, pyritic, and silty, and (2) dark red hematitic shale, locally micaceous, chloritic, and silty. Perhaps in some areas the hematitic shale is derived from weathering of the pyritic gray-green shale. These shales readily reflect metamorphism. The most common type is a dark gray-green chloritic micaceous metashale or clay-slate showing incipient foliation or partial development of slaty or fracture cleavage. The mica commonly has a "braided" appearance (from wrinkling?) and commonly shows orientation in two directions at a high angle (one parallel to bedding, the other parallel to an axial plane?).

Siltstone and sandstone.—Dark, fine-grained, angular, quartz siltstone, commonly chloritic, micaceous, dolomitic, pyritic, in part feldspathic and carbonaceous, is associated with the shale. In some areas development of new interstitial mica and chlorite indicates incipient to very weak metamorphism, and the rocks are low-rank metasiltstone. Sandstone is relatively rare in pre-Stanley sequences. Where present, it is associated with siltstone and is very fine-grained, mostly angular, and fairly well sorted; it is mineralogically similar to the siltstone. Two wells in Red River County (The Texas Company No. 1 Solomon and Magnolia Petroleum Company No. 1 Henry) penetrated fine-grained, angular, poorly sorted, tightly packed, hematitic quartzitic quartz sandstone; Johnston Petroleum Syndicate No. 1 Lady Alice encountered dolomitic metaquartzite.

Stratigraphy and Distribution

A reliable stratigraphic succession in subsurface pre-Stanley (pre-Tesnus) rocks cannot be established at this time from the data available; the rocks can only be compared with the exposed sections in the Ouachita and Marathon areas, bearing in mind that complex structure and unknown facies relations in the hundreds of miles between the two areas will not permit identification from *apparent* position in an apparent stratigraphic sequence; for example, a red shale beneath a green chert cannot be identified as Missouri Mountain simply because it is a red shale under something that looks like Arkansas novaculite.

Gross units can be identified with some confidence, however, and a sequence can be established in some wells.

The most distinctive subsurface unit is the assemblage of dark chert, siliceous shale, limestone, and dolomite. This is equivalent to the Bigfork chert (Upper Ordovician) of the Ouachita Mountains and can be identified with confidence as far south as Williamson County, Texas. The only unit with which it might be confused is the Arkansas novaculite which also contains dark chert and siliceous shale but which does not contain the limestone and dolomite characteristic of the Bigfork. Thus, dark cherts are not necessarily Bigfork, but dark chert, siliceous shale, and limestone-dolomite is Bigfork lithology.

West of the Llano uplift, dark chert has been encountered in a number of wells (Roland Blumberg No. 1 D. C. Knibbe, Comal County; Fred Turner, Jr., et al. No. 1 R. Linder, Kendall County; Plateau Oil Company No. 1 R. D. Garrison, Bandera County). Probably these rocks are Bigfork or Bigfork equivalents, but the only name that can be applied with certainty is "lower Paleozoic Ouachita facies." The Bigfork equivalent in the Marathon region, the Maravillas chert, has not been recognized in the subsurface of that area.

The other prominent body of siliceous rocks in both the Ouachita Mountains and Marathon region is the Arkansas novaculite or Caballos novaculite (Devonian-Mississippian) which is distinguished in both areas by prominent beds of white chert or novaculite. One would expect that this unit could be easily recognized in subsurface and could be used as a distinct marker, but white chert or novaculite was only rarely seen in subsurface between the two areas where it is so vividly exposed. In subsurface, the term Arkansas novaculite is applied to light-colored mostly tan or greenish chert and siliceous shale, commonly slightly dolomitic, which does not appear to be as thick as in the Ouachita Mountains and Marathon region. In the Ouachita Mountains the Arkansas novaculite includes dark red-brown bituminous pyritic spore- and radiolarian-bearing chert similar to that in the upper part of the Bigfork; Goldstein (personal communication, 1958) states that this type of chert occurs in the lower part of the middle member of the Arkansas novaculite. Thus, it is not possible to separate Arkansas novaculite from the Bigfork chert on the presence of dark chert containing organic matter; likewise, because of complex structure, a dark chert immediately overlain by Stanley is not *prima facie* evidence that the chert is Arkansas novaculite.

Dark gray-green to brown chloritic micaceous shale (commonly metashale) and fine chloritic micaceous quartz siltstone is identified as Womble where it occurs beneath a Bigfork sequence. However, where no Bigfork is recognized and penetration is limited, it is difficult to identify these shales and siltstones unless an Ordovician age can be established by graptolites. The Womble seems to be a great deal thicker in the Texas subsurface than in the Oklahoma outcrop (possibly as much as 3,000 feet in Grayson County), but according to Goldstein (personal communication, 1958), no unfaulted section of Womble exists in the Ouachita Mountains, and without a completely cored section in Texas to determine dip, the true thickness cannot be determined.

Several other Ouachita Mountain names have been used in the Texas subsurface—Missouri Mountain shale, Blaylock sandstone, Polk Creek shale, Mazarn shale, Crystal Mountain sandstone, Collier shale, and Stringtown shale. Inasmuch as the facies relations and persistence of these units are not yet fully known in the Ouachita Mountains, it seems hazardous to use them casually in subsurface studies. Missouri Mountain shale (Silurian), consisting of hard red and green slaty shale and siliceous shale with minor chert and sandstone, is a distinct unit in the Ouachita Mountains but not all hard red shale encountered in subsurface is necessarily Missouri Mountain. The red color is due to hematite; in north Texas red hematitic shales mark the top of the Paleozoic sequence and are developed by weathering of Stanley and Atoka shales. Blaylock sandstone (Lower Silurian) has been applied to fine-grained, fairly well-sorted, micaceous quartz sandstone which seemingly forms a sequence below light-colored cherts of the Arkansas novaculite, but this usage is hazardous also, as relations of the outcropping unit are not completely known. Blakely, Mazarn, Crystal Mountain, and Collier have been used to describe a metamorphosed sequence penetrated in Red River County (Johnston Petroleum Syndicate No. 1 Lady Alice) close to the McCurtain County outcrop of these formations. In the writer's opinion, it is difficult to justify the use of these formation names. In west Texas in Terrell County, R. E. Freeman No. 1 Barksdale penetrated a long section of black finely dolomitic and calcareous shales, commonly siliceous and containing bituminous material, and dark fine-grained spiculitic limestone, commonly silty, pyritic, siliceous, bituminous, and slightly fossiliferous; although incipiently to very weakly metamorphosed, these rocks resemble the Marathon limestone and are identified as Marathon (?). Table 4 lists wells in which formal stratigraphic names have been applied to the pre-Stanley sequence.

Inspection of the map (Pl. 2) shows that in outcrop and subcrop pre-Stanley Ouachita facies rocks occur (1) in relatively small discontinuous areas along the structural front of the Ouachita belt and (2) in broad anticlinoria in the interior parts of the frontal zone where it is broadly developed in the Marathon and Ouachita salients. Studies in the Ouachita Mountains and data from wells indicate that the older rocks which occur along the front of the belt have been raised along frontal overthrusts. From Oklahoma to Bell County in central Texas the oldest unit in the allochthonous Ouachita plates is Womble shale; thus, the displaced Ouachita plates all seem to have slid on Womble shale. West of the Llano uplift a narrow zone of lower Paleozoic Ouachita facies rocks fringes the front of the Ouachita belt, but it is difficult to recognize Ouachita Mountains or Marathon area units in this area. Overthrust relations in Magnolia Petroleum Company No. 1 Ed Below, Kendall County, the pattern of the rocks in subcrop, and abrupt changes from Ouachita to foreland facies suggest that the same relations prevail as in the northern limb of the belt—that the lower Paleozoic Ouachita rocks in the subcrop occur along a belt of overthrusting.

In the complex area of southern Val Verde County, lower Paleozoic Ouachita rocks form a narrow zone between Val Verde basin sedimentary rocks and highly sheared low-grade metamorphic rocks. The area is interpreted as one in which the Ouachita belt was thrust strongly against a buttress of high-standing Precambrian rocks, and the lower Paleozoic Ouachita facies rocks are represented on the map as part of a dislocated plate (p. 172 and Pl. 2).

In the Ouachita Mountains the largest exposures of pre-Stanley rocks form a major east-west-trending anticlinorium in Montgomery, Garland, and Saline counties, Arkansas, and in McCurtain County, Oklahoma—the Broken Bow—Benton anticlinorium. Subsurface information indicates that the anticlinorium trends southwestward into the subsurface in Texas (Pl. 2). Smaller exposures of pre-Stanley rocks in the Ouachita Mountains occur to the northwest along overthrust faults or as windows. In the Marathon area lower Paleozoic rocks are exposed in the Marathon and Dagger Flat anticlinoria. Another anticlinorium, largely concealed, probably occurs southeast of the Dagger Flat structure and includes the Persimmon Gap and Jones ranch exposures of older rocks. More such uplifts probably exist in the concealed area of the Marathon salient. The lower Paleozoic Ouachita rocks in Terrell County may be part of such an anticlinorium.

TABLE 4. *Wells in which pre-Stanley (pre-Tesnus) Ouachita facies formations have been identified.*

COUNTY and WELL NAME	FORMATION	INTERVAL (feet)	REFERENCE[1]
BELL COUNTY—			
Nolan Bell Oil Co. No. 2 Wm. Bacon	Womble shale(?)	T/896[2]	
B. F. Gilchrist No. 1 Curb-Fee	Bigfork chert	1,200–2,015	
Mellon Oil Co. No. 1 Noah Bailey	Arkansas novaculite Bigfork chert	2,500–3,790 3,500(?)–3,790	Sellards (1931b, p. 821) Goldstein (pers. comm., 1955)
Shell Oil Co. No. 1 C. E. Massie	Arkansas novaculite Bigfork-Womble	4,700±–4,800± 4,800±–5,050	
Eclipse Oil Co. No. 2 Slayden	Silurian Arkansas novaculite Missouri Mountain(?) Bigfork chert	710–850 935–1,050 940 1,000, 1,050	Sellards (1931b, p. 821) Goldstein (pers. comm., 1955)
COLLIN COUNTY—			
Deep Rock Oil Corp. No. 1 W. M. Sherley	Bigfork chert Womble shale	3,930–5,400	
COMAL COUNTY—			
Roland Blumberg No. 1 D. C. Knibbe	Arkansas novaculite(?) Blaylock sandstone(?) Bigfork chert(?) Womble shale	685–690 1,340–1,350 1,535–1,540 1,895, 2,015–2,020, 2,175	Goldstein (pers. comm., 1958)
CORYELL COUNTY—			
General Crude Oil Co. No. 1 Earnest Day	Arkansas novaculite(?) Bigfork chert Womble shale(?)	7,400±–9,275	
ELLIS COUNTY—			
John Mitchell No. 1 J. L. Rush	Arkansas novaculite Missouri Mountain shale Polk Creek shale Bigfork chert	T/2,098 T/2,416 T/3,793 T/3,846	H. J. Morgan, Jr., (pers. comm., 1956)
FANNIN COUNTY—			
Sun Oil Co. No. 1 Tucker	Bigfork chert(?)	3,755–3,854	
GRAYSON COUNTY—			
Continental Oil Co. No. 1 B. F. Armstrong	Arkansas novaculite Missouri Mountain(?) shale Bigfork chert Womble shale	2,100–2,110, 2,170–2,180 2,260–2,270 2,470–2,480, 2,490–2,500, 2,520–2,530, 2,570–2,580, 2,590–2,600, 2,700–2,710, 2,810–2,820, 2,950–2,970 3,000–3,010	
A. G. Hill No. 1 Ione Carter	Arkansas novaculite Missouri Mountain shale Polk Creek shale Bigfork chert Womble shale Fault and Bigfork chert Womble shale	T/2,280 T/2,370 T/2,440 T/2,700 T/2,185 T/3,300 T/3,500	W. J. Wilson (pers. comm., 1956)
Olson Drlg. Co. No. 1 Southwestern Life Insurance Co.	Arkansas novaculite Missouri Mountain shale(?) Polk Creek shale(?) Bigfork chert Womble shale	T/4,485 T/4,790 T/4,860 T/4,890 T/5,270	Goldstein (pers. comm., 1955)
Olson Drlg. Co. No. 1 Utiger	Arkansas novaculite Missouri Mountain shale(?) Bigfork chert Womble shale	T/950 T/1,270 T/1,320 T/2,030	Goldstein (pers. comm., 1955)
Pan American Prod. Co. No. 1 J. Umphress	Womble shale	3,730–6,175	Goldstein (pers. comm., 1955)

COUNTY and WELL NAME	FORMATION	INTERVAL (feet)	REFERENCE[1]
GRAYSON COUNTY (continued)—			
Peter and Johnson No. 1 J. A. O'Dell	Missouri Mountain shale Polk Creek shale		Miser and Sellards (1931, p. 815)
W. J. Rutledge No. 1 M. E. Williams	Bigfork chert	3,530–3,540, 3,800–3,810	
Simpson-Fells Oil Co. No. 1 G. W. Wall	Bigfork chert Womble shale Bigfork chert Stringtown shale	T/900 T/1,374(?) 900–1,552 1,552–2,515	Goldstein (pers. comm., 1955) Miser and Sellards (1931, p. 818)
Starr Oil Co., Inc., No. 1 Blankenship	Womble shale	2,010–5,230	V. E. Tims (pers. comm., 1957)
Verne Dumas Co. et al. No. 1 M. E. Williams	Bigfork chert(?)		
HAYS COUNTY—			
E. A. Bucklin No. 1 A. A. Elsner	Missouri Mountain shale Polk Creek shale	725–835	Sellards (1931b, pp. 822, 827)
KENDALL COUNTY—			
J. S. Abercrombie and Harrison Oil Co. No. 1 Lena Kunz and Joe Nickel	Missouri Mountain shale(?)	2,252	Goldstein (pers. comm., 1955)
Magnolia Petr. Company No. 1 Ed Below	Arkansas novaculite Missouri Mountain shale (?) Womble shale(?)	1,007–1,365	
Fred Turner, Jr., et al. No. 1 R. Linder	Missouri Mountain shale(?) Bigfork chert	1,100 T/1,450, 1,481	Goldstein (pers. comm., 1955)
LAMAR COUNTY—			
Clark & Ogg No. 1 Smiley	Bigfork chert and Womble shale(?)	3,195–3,355	
Cosden Petr. Co. No. 1 W. T. Adams	Blaylock sandstone(?)	2,820–3,065	Goldstein (pers. comm., 1955)
McLENNAN COUNTY—			
Daniel Oil Co. No. 1 Elizabeth W. Estes	Bigfork chert(?)	2,598, 2,650	
Delta Drlg. Co. No. 1 C. Horstman	Bigfork chert	1,120–2,259	
Hodges et al. No. 1 Lawrence	Bigfork chert(?)	1,313–1,600	Sellards (1931b, p. 823)
St. Louis Oil Pool No. 1 Stuart	Bigfork chert	1,235±–3,500	
RED RIVER COUNTY—			
Johnston Petr. Syndicate No. 1 Lady Alice	Womble shale Blakely sandstone Mazarn shale Crystal Mountain sandstone Collier shale	1,673–4,520	Miser and Sellards (1931, p. 812)[3]
Joe White et al. No. 1 Kurth Lumber Co.	Bigfork chert(?)	2,133–2,139	
TERRELL COUNTY—			
Milham Oil Corp. No. 1 Bassett	Woods Hollow shale(?)	1,215–3,565	Lewis (1941, pp. 78–79)
R. E. Freeman No. 1 Barksdale	Marathon limestone(?)		
WILLIAMSON COUNTY—			
W. E. Green No. 1 Lehman	Arkansas novaculite or Bigfork chert	2,470–2,990 (scattered samples)	
S. L. Carpenter No. 1 S. J. Seward	Bigfork chert Womble shale	1,630–2,008 (scattered samples)	

[1] If no other reference is given, the identification was made in this study.
[2] T/=top.
[3] Sequence penetrated in well is described as "comparable in lithology to . . ." the Ouachita Mountain section.

MISSISSIPPIAN-PENNSYLVANIAN ROCKS OF OUACHITA FACIES

Stanley Shale, Tesnus Formation, and Mississippian-Pennsylvanian Rocks Undivided (Tesnus?)

The Stanley and Tesnus formations, as well as probably correlative rocks of Mississippian-Pennsylvanian age in the subsurface of south-central Texas, are thick bodies of thinly interlayered shale and sandstone of flysch type; they comprise most of the frontal zone of the Ouachita belt. They are for the most part unmetamorphosed near the foreland margin of the belt and incipiently to very weakly metamorphosed to the south and east. Throughout most of the Ouachita belt they are strongly folded and faulted and locally show incipient to well-developed slaty cleavage. They are commonly veined by quartz, carbonate, quartz-bitumen, and, more rarely, chlorite; chlorite veinlets are restricted to the slightly metamorphosed sequences.

Shale.—Stanley-Tesnus shale is mostly dark (dark gray, green gray, and black) clay shale, commonly silty, carbonaceous, micaceous, and chloritic. Weaver (1958, p. 299) described the Stanley shale as dominantly illite-chlorite with kaolinite present in the southern Ouachita Mountains. Fan and Shaw (1956) described the Tesnus shale as illite and mixed-layer chlorite-vermiculite (lower unit) and illite-montmorillonite (upper unit). In some parts of the Ouachita belt these shales have been deformed and subjected to varied degrees of metamorphism (mostly incipient to very weak). Deformed and very weakly metamorphosed shale (meta-shale and clay-slate) commonly has a "braided" appearance under the microscope (due to wrinkling?) with two directions of orientation of clay-mica-chlorite at a high angle. Incipient axial plane and fracture cleavage occurs locally. Mica-chlorite is well developed in the partly reconstituted rocks.

Sandstone.—Stanley-Tesnus sandstone is mostly hard gray to greenish-gray, fine-grained (0.10 to 0.20 mm), angular, poorly sorted, argillaceous feldspathic quartz sandstone, commonly carbonaceous, micaceous, and chloritic, and rarely calcareous or dolomitic (Pl. 6, B, C, D; Pl. 7, B, C, D). Calcite and dolomite are more abundant in the western segment of the belt than in the northern segment; cone-in-cone carbonate occurs in Daniel Oil Company No. 1 Elizabeth W. Estes in McLennan County, Texas Minerals No. 1 Snowden in Fannin County, and Peter Oil and Gas Company, Inc., No. 1 Butcher in Grayson County (Pl. 8, B). Locally the sandstone contains abundant rock fragments including chert, slate-phyllite, quartz mosaic, and in the western area microgranular feldspathic fragments, as well as micaceous-chloritic material. These rocks are graywackes. In one area (Medina County, Texas) the rocks probably include conglomerates or breccias made up of sheared granitic rock fragments and fragments of volcanic rocks, schist, and limestone. The quartz of Stanley-Tesnus sandstone consists predominantly of undulose to strongly undulose grains, composite grains, and grains of bubbly vein quartz. The feldspar is mostly plagioclase (albite-oligoclase) with subordinate microcline and microcline microperthite in the western segment. The heavy mineral fraction is garnet, zircon, tourmaline, apatite, magnetite-ilmenite, and leucoxene; much angular garnet occurs in the sandstone in the northern segment between Travis County and the Red River; garnet is less common southwest of the Llano uplift and is very rare farther west. In places the matrix of the sandstone is partly reconstituted through incipient to very weak metamorphism—in some samples the new mica-chlorite is oriented and in others directional fabric is lacking. Dark, hard, angular, fairly well-sorted, argillaceous micaceous chloritic quartz siltstone, commonly feldspathic, occurs with the sandstone. In southeast Oklahoma and northern Texas in the vicinity of the buried Arbuckle element, the Stanley is more calcareous and contains more potassium feldspar than elsewhere; in Carter Oil Company No. 1 Loyd, Bryan County, Oklahoma, large subhedral potassium feldspar grains and a fragment of granite occur in sandstone from the Stanley, and in Damon No. 1 Chaffin, Fannin County, Texas, Stanley sandstones contain abundant potassium feldspar.

Jackfork Sandstone

The Jackfork sandstone forms a large part of the frontal zone of the Ouachita belt in the Ouachita Mountains salient and extends southward in the subsurface into Fannin County, Texas; it has not been recognized farther south. The Jackfork is a thick mass of interlayered sandstone and shale; excepting for local incipient to very weak metamorphism in areas of maximum deformation, it is not metamorphosed. In places it is cut by veinlets of quartz, carbonate, and bitumen. Like the Stanley, the Jackfork has been strongly deformed, and locally cleavage is developed.

Sandstone.—The Jackfork sandstone is hard, gray, fine- to coarse-grained, mostly subangular, mostly well-sorted, quartz sandstone, commonly quartzitic and commonly containing abundant rock fragments (vein quartz, quartzite, chert, minor slate-phyllite). The heavy mineral suite includes zircon, rutile, tourmaline, apatite. The low clay-mica and feldspar content of Jackfork sandstones and the absence of garnet make them easy to distinguish from Stanley and Atoka sandstones. In areas of strong deformation, the matrix of the Jackfork sandstones is partly reconstituted.

Shale.—Shale in the Jackfork is dark gray to green clay shale, commonly silty and commonly containing carbonaceous plant debris, locally spiculitic (Pl. 8, A). According to Weaver (1958, p. 299), it is illite-chlorite, with minor amounts of kaolinite and mixed-layer illite-montmorillonite; this shale contains much less chlorite than that of the Stanley. In areas of strong deformation Jackfork shales show cleavage and partial reconstitution.

Atoka Formation

The Atoka formation (1) occurs well within the Ouachita belt in the Ouachita Mountains salient; (2) forms a thin band within the front of the belt in some areas in Texas (and probably also in Mississippi); and (3) occurs also on the foreland from Mississippi to far west Texas. Although Atoka lithology is mostly sandstone and shale, rocks called Atoka vary greatly in their sandstone/shale ratio and in the character of the sand; along the axes of the deep foreland basins, the Atoka formation is mostly shale but on the margins of the basins it is more sandy. Moreover, the sand within the Atoka was derived from many different sources. In the McAlester basin, the Atoka beds on the side of the basin bounded by the Ouachita belt contain sand from a southern source, but to the northeast the Atoka contains sand derived from the Ozark uplift, and to the west the sand came from the Arbuckle uplift (C. C. Branson, personal commmunication, 1958). In the Fort Worth basin, most of the Atoka sand was derived from the Ouachita belt to the east, but in the southern and northern parts of the basin, the Llano uplift and the Muenster arch contributed detritus. Atoka beds locally are strongly deformed and cleavage is developed in the shales; the rocks are cut by veinlets of quartz, carbonate, and quartz-bitumen.

For purposes of this report, studies of Atoka lithology were confined to the parts within or immediately adjacent to the Ouachita belt. Here, the Atoka is similar to the Stanley and some Atoka sandstones cannot be distinguished from Stanley sandstones, but generally, the sandstones of the two units can be distinguished by differences in mineralogy and texture (p. 18).

Sandstone.—Atoka sandstone within the Ouachita belt is hard (locally quartzitic), gray, fine- to coarse-grained, angular to subround, poorly to fairly well-sorted, quartz sandstone, commonly argillaceous, commonly calcareous, locally micaceous. In places close to the Ouachita front these sandstones contain abundant mica and rock fragments derived from the Ouachita belt, including metamorphic rock fragments (slate, phyllite, metaquartzite), chert (Bigfork and Arkansas novaculite types), sandstone, shale, and vein quartz. The quartz in Atoka sandstone is of mixed types with abundant strongly undulose and composite grains and large amounts of bubbly vein quartz. The feldspar is plagioclase, but it occurs in much smaller amounts than in Stanley sandstones (potassium feldspar occurs in Atoka sandstones in the frontal basins where uplifts of the foreland basement contributed detritus). Zircon, garnet, apatite, tourmaline, rutile, leucoxene, and magnetite-ilmenite make up the heavy mineral suite; angular and modified garnet fragments similar to garnet in Stanley sandstones occur in some samples, but it is not so common or abundant as in the Stanley. Where the Atoka has been strongly deformed (close to the Llano uplift), incipient reconstitution of the clay-mica matrix is indicated by sprouts of new sericite and chlorite, but metamorphism in Atoka rocks is generally rare.

Shale.—Atoka shale within the Ouachita belt is very similar to Stanley shale; it is dark clay shale, commonly silty, micaceous, carbonaceous, chloritic. According to Weaver (1958, p. 299), the Atoka shales south of the frontal Choctaw fault in the Ouachita Mountains are illite-chlorite with lesser amounts of kaolinite and mixed-layer clay.

Dimple and Haymond Formations

The Dimple and Haymond formations (Morrowan and Atokan respectively) in the Ouachita structural belt in the Marathon region (P. B. King, 1937) are not separately distinguished on Plate 2 of this report; their respective outcrops are grouped with the Tesnus formation. They undoubtedly extend beneath the Cretaceous cover into the subsurface east and southwest of the exposures of the Marathon Basin, but well control is insufficient to attempt to separate them from the Tesnus or to map them individually. In the northern part of the Ouachita belt, the post-Stanley beds (Jackfork and Atoka formations) *within* the frontal zone of the belt seem to be restricted to the broadly developed Ouachita Mountains salient (p. 165); likewise, in the western segment the occurrence of younger rocks (post-Tesnus beds) within the deformed belt seems to be more or less restricted to the Marathon salient where the frontal zone is broadly developed.

Stratigraphy and Distribution of Mississippian-Pennsylvanian Rocks

No attempt is made herein to work out a stratigraphic sequence in the thick strongly deformed body of Mississippian-Pennsylvanian clastic rocks that comprises most of the frontal zone of the Ouachita belt; the main problem is to distinguish major units—Stanley shale, Tesnus formation, Jackfork sandstone, and Atoka formation. A combination of sandstone petrography and X-ray analysis serves to identify these formations within the limits of accuracy required for a regional study. Well samples indicate that the lithology determined in outcrops persists into the subsurface. Tuffaceous beds, siliceous shales, and cone-in-cone carbonate occur in the Stanley in north-central Texas, and siliceous radiolarian-bearing shale occurs in the Jackfork in Fannin County. Scattered cores show that the rocks are steeply dipping, sheared, and slickensided. Because of deformation, faulting, and lack of continuously cored sections, it is uncertain whether there is any major change in the thickness of these units in the subsurface.

In the northeast-trending limb of the Ouachita belt between the Ouachita Mountains in southeast Oklahoma and Travis County in central Texas, the frontal zone of the Ouachita belt is mainly Stanley formation (Pl. 2). Throughout this segment, the Stanley appears to be identical with the Stanley shale in the western Ouachita Mountains; Stanley sandstone is characteristically dark, fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone, commonly micaceous and chloritic, with abundant garnet in the heavy mineral fraction. The feldspar is sodic plagioclase and the mica is sericite-muscovite. Tuffaceous material probably correlative with the tuff in the lower part of the Stanley in the Ouachita Mountains (Hatton tuff lentil) is found in Hill-Texas Oil Company No. 1 C. Weatherby in Hill County, Texas, and as hard green tuffaceous siliceous shale at the base of the Stanley in General Crude Oil Company No. 1 Earnest Day in Coryell County. Tuffaceous material is also present in an incipiently to very weakly metamorphosed red shale-siltstone sequence in Hunt County (Humble Oil & Refining Company's No. 1 Norman and No. 1 Rutherford) which is probably Stanley; red beds are not typical of the Stanley in the Ouachita Mountains, but in north Texas a zone of red beds seems to have been formed on the surface of Paleozoic rocks as a result of pre-Cretaceous weathering. Goldstein (p. 340) interpreted the granite and feldspar fragments in the Stanley in Carter Oil Company No. 1 Loyd in Bryan County, Oklahoma, as probably of pyroclastic origin because the sandstone matrix in the sample (3,649 feet) is tuffaceous. Another possible interpretation is that some clastic material in the Stanley in this area was derived from a foreland uplift (Arbuckle element?) during Mississippian time. The abnormally high amount of calcareous material in the Stanley in this same area might also be the result of foreland-derived sediments.

Southwest and west of Travis County, Texas, where the Ouachita belt wraps around the Llano uplift and continues westward, Mississippian-Pennsylvanian rocks retain the over-all character of the Ouachita facies but change sufficiently that the name Stanley is no longer applicable. In part, this change is more apparent than real due to the advance of very weak metamorphism farther into the frontal zone (p. 122 and Pl. 2), but there are also changes in the composition of the sandstone. Here (Hays, Comal, Blanco, Kendall, Bexar, Bandera, Medina, and Uvalde counties) the northern part of the frontal zone of the Ouachita belt seems to consist of very weakly metamorphosed Mississippian-Pennsylvanian and older rocks of Ouachita facies that have been thrust over the foreland; farther to the south, unmetamorphosed Mississippian-Pennsylvanian rocks occur immediately north of the Luling overthrust front (Pl. 2). The overall petrography of the Mississippian-Pennsylvanian sandstones shows the characteristics of the Ouachita facies—the rocks are mostly hard, gray to gray-green, fine-grained, angular, poorly sorted, argillaceous micaceous chloritic feldspathic quartz sandstone and dark silty shale. In detail, however, there are significant differences:

(1) The feldspar content of the rocks is higher than in the northern segment of the Ouachita belt and many of the sandstones are true arkose; potassium feldspar, rarely seen to the north, is commonly present in this area, although still subordinate to plagioclase in amount.

(2) Mica and chlorite are more abundant in this area and include faded and bleached biotite which does not occur in the Stanley to the north.

(3) Rock fragments southwest of the Llano uplift, although mainly phyllite-slate, chert, and quartz mosaic like those to the north, also include a few fragments of a microgranular feldspathic igneous rock.

(4) Calcite and dolomite are commonly present in these sandstones in small amounts.

(5) Carbonaceous and bituminous material is relatively abundant.

(6) Garnet is not a prominent heavy

mineral (except in Clarence Newton No. 1 Check Ranch in Kendall County); the usual suite is zircon, apatite, tourmaline, and magnetite-ilmenite.

It should be noted that Weaver (p. 157) reported relatively abundant kaolinite in the shales in this area.

The rocks are cut by the same suite of quartz, carbonate, chlorite, and bitumen veinlets; chlorite veinlets are most common in very weakly metamorphosed rocks. The shales show the same structural characteristics as to the north—wrinkling and development of incipient axial plane and fracture cleavage.

In samples from John I. Moore No. 1 Alfred J. Wurzbach in Medina County, fragments of muscovite-biotite granodiorite, in part cataclastically altered, as well as fragments of trachyte porphyry, and a few pieces of calcilutite and muscovite schist are associated with sandstone and metashale fragments. The exotic fragments (mostly igneous rocks) in this well are probably in conglomerate or breccia beds within a sandstone-metashale sequence of Mississippian-Pennsylvanian age (p. 157).

The frontal zone of the Ouachita belt, which can be mapped as a continuous tectonic unit from western Arkansas to Medina County, Texas, disappears in Duval and Kinney counties. Very little well control is available in this area, but there is a real structural discontinuity in the frontal zone and not an apparent discontinuity caused by a paucity of control points, because farther west in western Kinney and Val Verde counties highly sheared low-grade metamorphic rocks characteristic of the interior zone of the Ouachita belt are bordered on the north by foreland facies rocks and there are no intervening frontal zone Ouachita rocks. If Mississippian-Pennsylvanian rocks were deposited in the Ouachita geosyncline in this area, they must have been overridden by an allochthonous plate of metamorphic rocks of the interior zone of the belt (pp. 172–173).

In the Marathon region part of another salient of the Ouachita belt is exposed where the frontal zone is broadly developed. Here, the oldest Mississippian-Pennsylvanian rocks of Ouachita facies form the Tesnus formation, a flysch-type unit of interlayered sandstone and shale. East and southwest of the Marathon Basin well control is poor. Tesnus beds, variably metamorphosed, have been identified in wells in Terrell County east of the Marathon area; the Tesnus also crops out south and southwest of the Marathon uplift in Persimmon Gap and in the Solitario. The Tesnus, therefore, probably makes up a large part of the subcrop of the frontal zone of the Ouachita belt in Terrell and Brewster counties. The Tesnus is similar to the Stanley and to the undivided Mississippian-Pennsylvanian rocks south and west of the Llano uplift; in petrographic detail the Tesnus sandstones are more like those south and west of the Llano uplift than like the Stanley beds in the north limb of the belt. Tesnus sandstones contain abundant chlorite, faded second-cycle biotite, and potassium feldspar in addition to the more abundant plagioclase. The feldspar content of Tesnus sandstones is low compared to the highly feldspathic sandstones of the frontal zone in south-central Texas. Farther south in Persimmon Gap Tesnus sandstones seem to be more feldspathic. The general similarity is such that the Mississippian-Pennsylvanian rocks which comprise the frontal zone of the Ouachita belt in Hays, Blanco, Kendall, Bexar, Bandera, Medina, and Uvalde counties are tentatively assigned to the Tesnus (?).

DARK CLASTIC ROCKS OF UNKNOWN AGE

Lithologic Description

East and south of the Stanley and pre-Stanley rocks that form the foreland side of the frontal zone of the Ouachita belt is a body of dark clastic rocks that do not crop out in any of the exposed parts of the belt. This unit lies partly in the frontal zone and partly within the highly sheared interior zone, east and south of the Luling overthrust front (Pl. 2). The unit includes two distinct metamorphic facies. Superficially, the highly-sheared weakly metamorphosed rocks east and south of the Luling front look very different from the very weakly metamorphosed rocks of the frontal zone, but the basic lithology and mineralogy are the same in both zones—the rocks are dark fine-grained to coarse-grained clastic sedimentary rocks containing abundant carbonaceous or graphitic material, mica, and dolomite as well as calcite, hematite, and pyrite. The main mineralogical difference between the two zones is that to the southeast, as a result of extreme shearing and higher grade metamorphism, carbonaceous matter was converted to graphite, and argillaceous material, second-cycle mica and chlorite, was to a greater extent reconstituted to new sericite and chlorite. Physical differences between the two zones are much plainer; east and south of the Luling front the rocks show pronounced dynamic structures such as slaty cleavage, fracture cleavage, foliation, microfolding and microfaulting, contortion, and flowage structures.

In the zone of very weak metamorphism the rocks are mostly (1) gray and black silty micaceous metashale and sericite-chlorite clay-slate, commonly carbonaceous or graphitic, pyritic, locally dolomitic, and siliceous (Pl. 9, A); (2) dark angular chloritic micaceous quartz siltstone or metasiltstone, commonly dolomitic (less commonly calcareous), carbonaceous, locally feldspathic, hematitic, and pyritic; and (3) dark, fine- to coarse-grained, angular, poorly sorted, chloritic micaceous argillaceous quartz sandstone or metasandstone, commonly calcareous or dolomitic, carbonaceous, locally feldspathic and containing abundant fragments of slate-phyllite, metaquartzite, and chert. These rocks have been invaded by numerous and locally massive veins of quartz, dolomite, calcite, chlorite, and bituminous material. The metashale and clay-slate are locally brecciated, crinkled, contorted, and have slaty cleavage.

South of the Luling front where shearing is extreme, reconstitution and metamorphic structures are better developed; the rocks are mostly (1) gray to black (rarely green) carbonaceous to graphitic chlorite-sericite slate, with augen of broken quartz veins, locally hematitic, pyritic, siliceous (Pl. 9, B, C, D); (2) dark angular carbonaceous sericitic chloritic quartz metasiltstone; and (3) dark, fine-grained, angular to subround, very poorly sorted, carbonaceous micaceous quartz metasandstone (rarely metaquartzite), commonly dolomitic, feldspathic, and with abundant rock fragments, locally pyritic. The rocks in this zone of weak metamorphism and high to extreme shearing are cut by both pre-deformation and post-deformation veins of quartz, dolomite, calcite, and chlorite; pre-deformation veins are broken and sheared into augen; veins are profuse and commonly massive. Metamorphic structures include foliation, slaty cleavage, contortion, and flowage around augen (Pls. 13, 14).

Several wells penetrating this unit in its western extension have encountered cataclastically altered granitic rock and fractured, sheared, and altered (chloritized-sericitized-albitized) andesite and basalt porphyry (p. 110). The igneous rocks are partly mylonitized—grains are fractured and granulated and feldspar is partly or wholly converted to sericite.

Stratigraphy and Distribution

On the subcrop of the Ouachita belt, dark clastic rocks of unknown age (not formally named) form an arcuate band east, southeast, and south of the Llano uplift; their maximum subcrop is more than 20 miles wide in Travis County, but they are unknown north of McLennan County and west of Bexar County. In the northern segment of the Ouachita belt, low-grade highly sheared rocks of the interior zone of the belt appear to have overridden very weakly metamorphosed shales and sandstones of this unit, but southward and westward in Travis County, part of the unit was included in the movement of the Luling overthrust front; from Travis County to Medina County extremely sheared black slates with strongly developed flowage structures suggest that the movement along the Luling front occurred within or at the base of these dark clastics. This is supported by the presence of partly mylonitized igneous rocks in Bexar and Medina counties (p. 110).

In Bexar County dark sheared and altered andesite or basalt lies within or beneath the sheared slates. Similar sheared and altered dark extrusive rocks occur farther west in Medina County and to the southwest in Maverick County, but in these areas the dark clastic sequence was not observed. Relations between this sequence and the intermediate to basic lava sequence are therefore uncertain, and it is not known whether the lavas in Bexar County are at the base of or within the sequence.

At the southeast edge of the known Ouachita belt, southeast of the Luling front and southeast of the subcrop of the phyllite-slate-metaquartzite sequence of the Luling area, one well (Quintana Petroleum Corporation No. 1 Lampkin) penetrated extensively veined dark slate and metasandstone similar to the dark clastic sequence. This well leads to speculation that the dark clastic unit might be repeated in the subcrop by successive thrusts southeast of the Luling front.

Age and Correlation

No fossils have been found in the dark clastic sequence. The carbonaceous material forms sooty masses and irregular streaks and no wood fragments were observed. The pattern of the outcrop suggests that the sequence is either (1) a large anticlinorium, thrust faulted to the south, or (2) a homoclinal (or synclinal) mass resting on the Stanley, dipping east and south, and thrust faulted to the south.

This unit may thus be part of the Stanley or a younger Mississippian-Pennsylvanian unit (structural interpretation No. 2). The dark shale-siltstone-sandstone lithology is not incompatible with that of the Stanley, but the rocks in general contain more finer material and more carbonate than the Stanley. Regional relationships indicate that the dark clastic sequence may be closer to the source area than the Stanley of the frontal zone, but if so, it should not contain more carbonate and fine-grained clastic material than the Stanley. It is also unreasonable to suppose that these dark clastics are correlative with younger Pennsylvanian units such as the Jackfork or Atoka. The dark clastic unit is strongly deformed; the most recent deformation occurred prior to the deposition of Pennsylvanian-Permian post-orogenic beds in Bexar County (H. A. Pagenkopf No. 1 Max Blum) perhaps during Des Moines time. Earlier deformations are indicated by the flysch facies of the Mississippian-Pennsylvanian sequence. Pre-shearing and post-shearing veins in the dark clastic sequence south of the Luling front show that these rocks were extensively veined and probably metamorphosed before the tectonic movements that caused the extensive shearing.

It would thus appear that the deformed dark clastic sequence is older than Middle Pennsylvanian and perhaps considerably older. These rocks may be a near-source facies of lower Paleozoic Ouachita facies rocks (structural hypothesis No. 1 above; Cross Section A-A′, Pl. 2); the associated volcanic rocks in Bexar County may be a product of the same period of volcanism that provided the silica for the lower Paleozoic chert sequences nearer to the foreland.

PHYLLITE, SLATE, METAQUARTZITE, MARBLE, AND SCHIST OF UNKNOWN AGE

LITHOLOGIC DESCRIPTION

Phyllite, slate, metaquartzite, marble, and schist occur in the subcrop east and south of the Luling front (Pl. 2) and constitute a distinct lithologic group. These rocks show low- to medium-grade metamorphism with a strong shearing component. The rocks are: (a) chlorite-sericite phyllite (or slate), commonly graphitic, hematitic, rutiliferous, locally albitic, biotitic, locally containing muscovite as porphyroblasts or unsheared relicts, rarely garnetiferous (Pl. 10, A, B, C; Pl. 11, C); (b) fine-grained metaquartzite, commonly graphitic, sericitic, chloritic, dolomitic, rutiliferous (includes metachert) (Pl. 11, A); (c) fine-grained biotite-chlorite-muscovite (and/or sericite) schist, commonly graphitic, garnetiferous, rutiliferous, calcareous; (d) fine-grained amphibole-epidote schist, locally calcareous, chloritic, sericitic; (e) fine-grained calcite marble, commonly dolomitic, quartzose, sericitic, graphitic, hematitic, locally albitic (Pl. 10, D; Pl. 11, B); and (f) fine-grained dolomite marble, commonly calcitic, quartzose, sericitic, graphitic, locally talcose(?). The rocks contain pre- and post-deformation veins of quartz, calcite, dolomite, chlorite, and epidote. Metamorphic structures are foliation, slaty cleavage, fracture cleavage, grain stretching, microfolding, microthrust faulting, micro-imbrication, wrinkling, convolution and contortion, and flowage around augen; the metaquartzites show granulation, suturing, and partial mylonitization; the calcite marbles show extensive twinning and grain deformation. The exposed rocks at the base of the Sierra del Carmen range in Coahuila, Mexico, just south of the Rio Grande (Pl. 2; Pl. 11, C) probably belong to this unit (Flawn and Maxwell, 1958).

All of these rocks show dynamic structures produced by strong shearing and a low to medium grade of regional metamorphism (Pl. 15). Medium-grade metamorphic rocks—indicated by presence of biotite, amphibole, garnets, and porphyroblastic muscovite—occur mostly in the extreme southern part of the belt in Caldwell, Wilson, Bexar, Frio, Zavala, and Val Verde counties. In some wells in this part of the belt (Plateau Oil Company No. 1 B. S. Harrison et al., Val Verde County; Magnolia Petroleum Company No. 1 McKinley, Frio County; Arkansas Fuel Oil Company No. 1 George Burkhardt, Bexar County), there is a suggestion of retrogressive metamorphism—muscovite is sheared to sericite, biotite is frayed and faded, garnets are broken (p. 124).

The various rock types are gradational and have a common mineral assemblage. They all contain the same essential minerals such as quartz, sericite-muscovite, chlorite, calcite, and dolomite, but the minerals occur in varying proportions to make phyllite-schist, metaquartzite, or marble. Graphitic material and rutile in finely dispersed needles are ubiquitous.

In addition to the sericite-chlorite-quartz-calcite-dolomite assemblage that makes up the bulk of the rocks of this unit, several wells in the southern part of the belt have penetrated highly sheared phyllite or fine-grained schist containing epidote and a finely fibrous colorless amphibole (Husky Oil Company No. 1 Rose-Robertson, Val Verde County; Park and Phillips No. 1 Flowers and Ward Ranch, Zavala County; and Bur-Kan Petroleum Company and Stanolind Oil and Gas Company No. 1 Lee Hubbard, Bexar County). These rocks also contain sericite, chlorite, quartz, and feldspar. They may be sheared igneous bodies included within the Ouachita belt or, in Husky Oil Company No. 1 Rose-Robertson, they may be part of a Precambrian metavolcanic terrane (p. 109).

Their metamorphic grade is similar to that of associated rocks—their mineralogy reflects their original composition (an igneous rock or a sedimentary rock with sufficient calcium, aluminum, iron, and silica to form amphibole and epidote).

Stratigraphy and Distribution

Phyllite, slate, metaquartzite, marble, and schist form the subcrop of the Ouachita belt in a continuous band from Navarro County, Texas, southwestward to Frio County, Texas. Continuity is lost in the Zavala and Maverick County area, but to the west phyllite, slate, metaquartzite, marble, and schist make up the subcrop in southern Kinney, Val Verde, Terrell, and Brewster counties, Texas, and northeastern Coahuila, Mexico. Similar rocks are exposed in the base of the western Sierra del Carmen scarp immediately south of Brewster County in northern Coahuila (p. 99). These strongly deformed rocks do not change in over-all lithology and metamorphic character from northeast to southwest and thus resemble the remarkably persistent lithologic units of the frontal zone which are more or less the same from the Marathon region in west Texas to the Ouachita Mountains of Oklahoma and Arkansas. The major difference between the Trans-Pecos metamorphic sequence and the rocks to the east lies in the presence of abundant calcite and dolomite marble to the west, whereas to the east carbonate rocks are comparatively rare. Interpretations from well cuttings, wherein lithologies are intimately mixed through long intervals, and the relations seen in the single exposure in the Sierra del Carmen indicate that in the western segment the sequence is thinly interlayered phyllite-schist, marble, fine-grained metaquartzite, and metachert; probably many of the wells drilled very steeply dipping or nearly vertical beds. Eastward in the Luling area and farther northeast the sequence is mostly phyllite with lesser fine-grained metaquartzite or metachert and rare marble; cores show that in many wells the rocks are nearly vertical.

In Freestone County, about 15 miles southeast of the highly sheared low-grade metamorphic rocks mapped in Navarro County, Humble Oil & Refining Company No. 1 Marberry encountered a very different sequence (p. 127). The predominant rock is a hard red quartzitic quartz sandstone containing abundant authigenic feldspar and derived from sedimentary rocks; metamorphism is very weak to weak, with a strong hydrothermal element and lacking the strong shear characteristic of rocks to the east. The rocks are unlike any others penetrated in the Ouachita belt to date; some geologists have speculated that the presence of these apparently very weakly metamorphosed rocks east of highly sheared low-grade metamorphic rocks suggests that the metamorphic terrane is flanked by unmetamorphosed Paleozoic rocks to the south and east and that the Ouachita belt is therefore relatively narrow. However, it is not sound to attempt large-scale tectonic interpretations on the basis of one well. In the Appalachian belt a wide variety of rocks occurs east of the Blue Ridge front, which in itself is discontinuous with many recesses, re-entrants, and windows. Possibly these red beds are post-orogenic rocks altered by younger igneous activity (p. 127).

Age and Correlation

The age of the highly sheared low-grade phyllite, slate, metaquartzite, marble, and schist is uncertain. Early investigators classed the rocks beneath the Cretaceous in the Luling field as Precambrian because of their metamorphic character and the presence of demonstrably Precambrian metamorphic rocks to the north in the Llano uplift. As more was learned about the Ouachita belt and it was recognized that some of the weakly metamorphosed rocks within the belt are Paleozoic, some geologists classed the phyllite, slate, metaquartzite, marble, and schist as Paleozoic in age (Barnes, 1948; Goldstein and Reno, 1952). The problem is still unresolved, but the possibilities can be clarified by examining the metamorphic rocks within the regional framework of the Ouachita belt.

The phyllite, slate, metaquartzite, marble, and schist sequence is part of an interior zone of the Ouachita belt. In the eastern counterpart of the Ouachita system, the Appalachian system, a zone of similar rocks adjacent to the frontal zone is known as the Blue Ridge province. These rocks are both late Precambrian and early Paleozoic in age, and the same may be true in the Ouachita belt. Probably rocks of different ages have been tectonically juxtaposed.

However, the consistent lithology of the phyllite, slate, metaquartzite, marble, and schist sequence indicates that these rocks constitute a gross lithologic unit as well as a metamorphic zone (p. 79). Therefore, although it is not unlikely that both Paleozoic and Precambrian rocks may occur within the interior of the Ouachita belt, the sequence mapped east and south of the Luling overthrust front probably does not include both Precambrian and Paleozoic rocks. Some rather tenuous and inconclusive evidence suggests that these rocks are early Paleozoic: (1) Absolute age determinations on mica from the Sierra del Carmen exposures, although not conclusive, point to a Paleozoic age for the metamorphism (George Edwards, Shell Development Company, personal communication, 1959); (2) small siliceous bodies resembling spicules were observed in Plumber and Schwab No. 1 Bud Roark in Brewster County (p. 235); (3) pre-Stanley rocks in the southwestern subsurface extension of the Broken Bow–Benton anticlinorium have been subjected to variable weak to low-grade metamorphism with a high shearing component, and the resulting sequence strongly resembles the rocks of the phyllite, slate, metaquartzite, marble, and schist belt in central and west Texas and northern Mexico; in Red River County, Texas, in Johnson Petroleum Syndicate No. 1 Lady Alice (p. 301) a graphitic dolomitic calcite marble occurs with sericite-chlorite slate and phyllite, and sericitic and chloritic metachert or fine-grained metaquartzite—this rock is nearly identical with the marble south of the Luling overthrust front; and (4) where Precambrian rocks have been encountered beneath metamorphosed Ouachita belt rocks in Kinney and Val Verde counties, the Precambrian rock is metavolcanic rock lithologically distinct from the phyllite, slate, metaquartzite, marble, and schist sequence.

The Subsurface Ouachita Structural Belt East of the Ouachita Mountains[11]

PHILIP B. KING

INTRODUCTION

In other chapters of this publication all available information, both surface and subsurface, has been assembled to portray the rocks and structures of the Ouachita belt of Paleozoic age from the Ouachita Mountains of Arkansas and Oklahoma, southwestward through Texas into Mexico. This chapter might be termed a reconnaissance survey of these same rocks and structures, eastward from the Ouachita Mountains.

In central Arkansas the exposed rocks and structures of Paleozoic age in the Ouachita Mountains pass eastward beneath Cretaceous, Tertiary, and Quaternary deposits of the Mississippi embayment. Obviously, they extend farther—but where? Three hundred and fifty miles to the east the rocks and structures of Paleozoic age in the Appalachian Mountains pass southwestward beneath Cretaceous and Tertiary deposits of the Gulf Coastal Plain. Again, these obviously extend farther—but where? What is the relation between these two orogenic systems, both of which grew during about the same parts of Paleozoic time? If they join, what is the nature of their junction?

Partial answers to these questions are afforded by the records of wells which have penetrated Paleozoic and earlier rocks beneath Mesozoic and younger rocks of the Gulf Coastal Plain and Mississippi embayment. Nevertheless, penetrations of the Paleozoic and earlier rocks have so far not been made in some of the most critical areas, in many of which they lie at great depth. Even where penetrations have been made, some of the data are either meager, equivocal, or not available to this writer. Because of the fragmentary nature of the record, the interpretations made here are based partly on analogy with known relations in adjacent outcrop areas. To make these interpretations, it is necessary to review a much wider area than that occupied by the Ouachita system alone, including the exposed Paleozoic and earlier rocks in the southern part of the Appalachian system and the Interior Plateaus, and their subcrop extensions southward beneath the deposits of the Atlantic and Gulf Coastal Plains.

This review is based partly on published and partly on unpublished sources.

Drill records in the part of Arkansas lying generally eastward from the Ouachita Mountains have been reported on by Renfroe (1949), Maher and Lantz (1953), and Caplan (1954). In addition, Norman F. Williams, State Geologist, and William M. Caplan, both of the Arkansas Geological and Conservation Commission, have generously provided many unpublished data on this part of the State. The writer's compilation on southern Arkansas was much more cursory than elsewhere and consisted only of a review of the easily available literature.

Subsurface relations of the Paleozoic rocks in northern Mississippi and Alabama were summarized in a pioneer paper by Mellen (1947). Further details on some of the wells have been given by the Mississippi Geological Society (Dott and Murray, ed., 1954, pp. 4–7, sheet 1; Mississippi Geol. Soc., 1954, pp. 39–52; Frascogna, ed., 1957, pp. 12, 20, 40, 60, 78, 82, 86, 114, 128), by Welch (1959), and by Cropp (1960, pp. 360–362). A structure contour map on the top of the Mississippian in the

[11] Publication authorized by the Director, U. S. Geological Survey.

northern part of the Black Warrior basin is available (Everett, 1953, p. 36). In addition, all non-producing wells in Mississippi, including those which have penetrated Paleozoic rocks, have been listed and mapped by Beikman and Drakoulis (1958a, 1958b); these authors indicate the probable age of the lowest formation penetrated in each well but give few other details.

In Alabama, all logs of wells drilled prior to 1945 have been assembled by Bowles (1941) and Toulmin (1945). Logs of wells drilled in northwestern Alabama prior to 1955 which are based on sample studies have been given by McGlamery (1955). Records of wells drilled in Paleozoic and older rocks in northern Florida, southern Alabama, and southern Georgia are listed and interpreted in a fundamental paper by Applin (1951), and the results of a paleontological study of specimens from many of the same wells have been summarized by Bridge and Berdan (1951, 1952).

Besides this published record, the writer has had the use of petrographic reports on cores or samples from some wells drilled in Mississippi and Alabama, made by Peter T. Flawn of the Texas Bureau of Economic Geology, August Goldstein, Jr., of the Bell Oil and Gas Company, and Charles Milton of the U. S. Geological Survey, and the use of paleontological reports on some other wells by G. Arthur Cooper of the U. S. National Museum and Ellis L. Yochelson of the U. S. Geological Survey. Various petroleum geologists have generously furnished other well data, and their contributions are acknowledged at appropriate places in the summary of well data, Appendix, Part 3. Jean Berdan of the U. S. Geological Survey has informed the writer of results of her work on the Florida Paleozoic which are later than the published record. Isidore Zeitz and other geophysicists of the U. S. Geological Survey have contributed valuable advice on the interpretation of geophysical features. Finally, Paul L. Applin of the U. S. Geological Survey has been an unfailing source of assistance and counsel regarding well data in the southeastern states.

Results of the writer's study are presented on the accompanying map of part of the southeastern United States (Pl. 3). This shows the extent of various Paleozoic and older rock units, both in outcrop toward the north and in subcrop beneath the coastal plains toward the south. The units selected for mapping are mainly stratigraphic, but they are also of structural significance. Results of the writer's review can best be presented in terms of these units.

Tectonic Provinces

The area mapped is divisible into various tectonic provinces, which will be referred to in the ensuing discussion. In the Paleozoic and earlier rocks are the following provinces:

(A) The southeastern part of the Central Stable Region of North America, where gently tilted Paleozoic rocks form most of the surface, was the foreland of both the Appalachian and Ouachita orogenic systems. Toward the north the Paleozoic rocks are raised in the broad Nashville and Ozark domes. To the southeast along the front of the Appalachian system they are depressed into a shallow longitudinal basin beneath the Cumberland Plateau; to the southwest along the front of the Ouachita system they are depressed into the deeper longitudinal Arkansas basin. In the intervening area, mainly beneath coastal plain deposits, is the Black Warrior basin; this is of triangular rather than longitudinal outline because it lies in a recess between the converging Appalachian and Ouachita systems.

(B) The Appalachian system on the southeast consists of folded, faulted, and partly metamorphosed Paleozoic and older rocks, divisible into a succession of longitudinal provinces, and these into subdivisions which are here referred to as "belts." To the northwest is the Valley and Ridge province, consisting of deformed but not metamorphosed strata of Cambrian to Pennsylvanian age. Southeast of it are the Blue Ridge and Piedmont provinces, consisting of weakly metamorphosed sedimentary rocks, metamorphic, and plutonic rocks, partly of the same age as those in the Valley and Ridge province and partly older. Drill data indicate that the Appalachian system extends considerable distances beneath younger deposits in the adjacent coastal plains, both southwestward along the strike and southeastward across the strike.

(C) The Ouachita system on the southwest is composed of folded, faulted, and partly metamorphosed Paleozoic rocks; no older rocks are known. Much of its structure in the exposed area resembles that in the Appalachian Valley and Ridge province. Drill data indicate that the Ouachita system extends southward and southeastward a considerable distance beneath younger deposits of the Gulf Coastal Plain and Mississippi embayment.

(D) In northern Florida, Paleozoic and older rocks are entirely concealed by younger deposits, but they lie at relatively shallow depth and have been widely penetrated by drilling. Paleozoic rocks underlie an extensive area, termed the Suwanee basin, in which they are flat-lying or gently tilted and are not metamorphosed.

The Mesozoic and later rocks of the region form broad coastal plains, where they are tilted seaward at low angles. The plains are divided geographically into the Atlantic and Gulf Coastal Plains, but the characteristic stratigraphic and tectonic features of the Atlantic Coastal Plain extend somewhat west of its geographic boundary, into Alabama. Variations in the prevailing structure occur in the Peninsular arch in the northern part of Florida (which coincides in part with the Suwanee basin in the older rocks) and the Mississippi embayment, a transverse downwarp in the Gulf Coastal Plain that crosses the eastern end of the Paleozoic Ozark uplift and extends northward into southern Illinois.

Triassic(?)

Unfossiliferous rocks that are believed to be of Triassic age have been penetrated in a large area in the Gulf Coastal Plain in southeastern Alabama, southwestern Georgia, and northwestern Florida (McKee et al., 1959, pl. 5). The sedimentary rocks include red arkosic sandstones and shales. Associated with the sedimentary rocks are large volumes of mafic igneous rocks that were emplaced either as flows, shallow intrusives, or both (Applin, 1951, pp. 15–17). Some wells have been drilled from younger Mesozoic rocks, through Triassic(?) rocks, into rocks of Paleozoic or earlier age, but a well to the west in Alabama (well 1[12], Crenshaw County) penetrated 4,285 feet of red clastic rocks without reaching their base, and another well in the Florida panhandle (well 9, Walton County) penetrated 4,297 feet of similar rocks. These red rocks are at least partly of Triassic(?) age, but they include younger Mesozoic strata at the top.

Northeast of the main Triassic(?) area in Georgia, several outlying wells have penetrated mafic igneous rocks, probably intrusive into a prevailing terrane of metamorphic and plutonic rocks. These mafic intrusives are analogous to the extensive system of diabase dikes in the exposed part of the Piedmont province from Alabama northeastward, that are believed to be of Triassic age. The dikes in Georgia, which trend generally northwestward, have been described by Lester and Allen (1950).

These Triassic(?) sedimentary and igneous rocks are much like those of the Upper Triassic Newark group, which is exposed in the Piedmont province of the Appalachian system from North Carolina northeastward. The Newark group probably was deposited in longitudinal troughs not much more extensive than the present outcrop areas. Well data are insufficient to prove the form of the Triassic(?) deposits beneath the coastal plain; they may similarly occupy longitudinal troughs (Braunstein, 1958a), or they may have accumulated as a widespread blanket along the edge of a primitive coastal plain (McKee et al., 1959, p. 24 and pl. 9), as shown on the map (Pl. 3).

Permian(?)

Farther west, mainly in southern Arkansas, is the Eagle Mills formation (Weeks, 1938, pp. 962–964; Imlay, 1940a, pp. 8–15; Hazzard et al., 1947, pp. 484–486), another body of red, unfossiliferous clastic rocks. The Eagle Mills is commonly classed as of Permian(?) age, but its relations to other formations cannot be proved, as it is everywhere overlain unconformably by much younger Upper Jurassic or Cretaceous formations, and as no well has certainly reached its base, although thicknesses of as much as 4,600 feet have been penetrated. The Eagle Mills is evidently younger than the Ouachita orogeny; one well which entered the formation is only 17 miles south of outcrops of deformed Paleozoic rocks in the Ouachita Mountains. It is probably also younger than the Middle or Upper Pennsylvanian Morehouse formation, penetrated in one well to the south in Louisiana (well 23).

The Eagle Mills was originally thought to be an updip clastic equivalent of the Werner formation and Louann salt[13] farther south beneath the coastal plain, but these units are now generally believed to have been formed during a later sedimentary cycle (Hazzard et al., 1947, p. 483). The Werner and Louann are also classed as Permian(?) by some geologists but as of Jurassic(?) age by others (McKee et al., 1956, p. 2).

Red strata have been penetrated beneath

[12] See Appendix, Part 3, for all numbered wells.

[13] The stratigraphic names Werner formation, Louann salt, and Norphlet formation are used here as redefined by Hazzard *et al.* (1947), although these redefinitions have not been formally adopted by the U. S. Geological Survey. The stratigraphic concepts involved have been generally accepted, but opinions differ as to the validity of the Permian age which was suggested for the first two units.

proved Jurassic formations in some of the deeper wells in Mississippi and Alabama, in the area between typical occurrences of the Eagle Mills and the Triassic(?). Although various correlations of these strata have been proposed by geologists, the present study has not been sufficient to determine whether they are equivalent to the Eagle Mills on the west, the Triassic(?) on the east, or whether they include equivalents of both.

PENNSYLVANIAN

Rocks of the Pennsylvanian system are extensive in the foreland region northwest of the Appalachian Mountains and north of the Ouachita Mountains. They are generally missing within the Appalachian and Ouachita Mountains, at least partly because of erosion. However, they are preserved in deeper synclines in the southwest part of the Valley and Ridge province near Birmingham, Alabama (Butts, 1926, pp. 208–217). Moreover, the weakly metamorphosed Talladega belt farther southeast in the same region includes the Erin shale which contains fossil plants of probable Pennsylvanian age (p. 92). The Erin is part of the sequence and is actually a slate or phyllite, rather than a "shale" (Griffin, 1951, pp. 31–48); it is not in a window in a thrust sheet as has been claimed (Park, 1935). In the Ouachita Mountains most of the exposed rocks are older than the Pennsylvanian, but the Pennsylvanian Atoka formation is preserved in some of the deeper synclines.

In the Appalachian region and its foreland the Pennsylvanian rocks have all been assigned to the Pottsville formation. They are mainly shale and sandstone but include thin beds of conglomerate. Layers of coal are interbedded throughout, as well as layers containing marine invertebrate fossils, so that the Pottsville must be of mixed continental and shallow-water marine origin. The Pennsylvanian strata which are preserved are about 2,500 feet thick in the foreland area and more than 9,000 feet thick in the synclines in the Valley and Ridge province. At least part of this increase in thickness is the result of depositional variations.

Similar Pennsylvanian strata extend westward around the south end of the Nashville dome, across northern Alabama and into the subcrop in northern Mississippi. Here, they thicken southwestward into the Black Warrior basin, some wells penetrating as much as 8,000 feet of Pennsylvanian strata (Cropp, 1960, p. 360); the maximum thickness in the basin may exceed 10,000 feet. In the Black Warrior basin, coal layers are recorded throughout the Pottsville, and much of it is probably of mixed continental and marine origin, as farther east.

In the Arkansas basin[14] of Arkansas, north of the Ouachita Mountains, most of the Pennsylvanian is Atoka formation, although the Hartshorne sandstone and higher formations of Des Moines age are preserved above it toward the west. The Atoka is more than 19,000 feet thick close to the front of the Ouachita Mountains (Reinemund and Danilchik, 1957), but it thins northward to a feather edge along the flanks of the Ozark uplift. The Atoka formation west of the Mississippi embayment is on line of strike with the Pottsville formation east of the embayment and is probably correlative. However, its thicker parts are of marine origin and are not of continental origin as is part of the Pottsville.

Along the northwestern front of the Appalachian system most of the Pennsylvanian rocks are gently tilted, but they are turned up steeply on the flanks of marginal folds such as the Sequatchie anticline and are much folded in the synclines within the Valley and Ridge province near Birmingham, Alabama. Moreover, detailed studies in the Cumberland Plateau of Tennessee indicate that wide areas of seemingly little disturbed Pennsylvanian beds have been displaced extensively along

[14] The term Arkansas basin, and the term McAlester basin mentioned below, refer to different parts of the same feature, lying respectively in Arkansas and Oklahoma. The single term Arkoma basin has recently come into wide use for this feature (C. C. Branson, 1956a; Jordan, 1959).

bedding-plane thrusts (Wilson and Stearns, 1958, pp. 1290–1295). These thrusts may extend southwestward along the front of the Appalachian system, into Alabama.

In the Arkansas and McAlester basins of Arkansas and Oklahoma the Pennsylvanian rocks have been folded into a succession of anticlines and synclines, parallel to those in the Ouachita Mountains and diminishing in intensity away from the mountains. Incipient metamorphism is indicated by carbon ratios in the coals (Hendricks, 1935, pp. 946–947); although the ratios vary much in detail they increase generally southward, as a result of pressures directed northward from the mountain area.

In subcrop in Mississippi similar tilted, folded, and weakly metamorphosed clastic rocks probably form a belt of some width along the southwest flank of the Black Warrior basin; such a belt is indicated on the accompanying geologic map (Pl. 3) although it is admittedly somewhat hypothetical. The clastic rocks penetrated by wells in this belt have been assigned to the Pennsylvanian by many geologists, and no equivalents of the Mississippian Stanley and Jackfork formations have been reported. The rocks would thus seem to be the structural and stratigraphic counterparts of the Pennsylvanian rocks in the Arkansas basin immediately north of the main Ouachita system in the Ouachita Mountains of Arkansas and Oklahoma. The rocks in many of the same wells in Mississippi have been ascribed to a "Ouachita facies" by some geologists, but this can be true only in the gross meaning of that term. In Attala, Neshoba, and Lauderdale counties, east-central Mississippi, wells which have penetrated these rocks (wells 35–38) lie northeast of an extensive subcrop belt of lower Paleozoic carbonate rocks which is here interpreted as an extension of the Appalachian Valley and Ridge province. Petrographic examination of rocks from one of these wells (well 35) by August Goldstein, Jr. (written communication, 1960) indicates that they have been weakly metamorphosed. Nevertheless, the rocks in this well, and others nearby, must be part of a structural element that is different from the Ouachita belt as it is understood farther west.

Mississippian

The Mississippian system crops out extensively along the front of the Appalachian system, as well as southeastward into the Valley and Ridge province and westward into the foreland area south of the Nashville dome.

Along the front of the Appalachian system the Mississippian is about 1,200 feet thick and forms alternating thick limestone units and thinner sandstone and shale units (Butts, 1926, pp. 162–207). The Lower Mississippian is thin, and most of the sequence belongs to the Upper Mississippian, or Chester series, the latter being divided into many thin, widely traceable formations and members.

Southeastward in the Valley and Ridge province the Mississippian is preserved in many downfolded or downfaulted remnants, which are more extensive than those of the Pennsylvanian in the same province. Here, the formations of the Chester series are partly or wholly replaced southeastward by the Floyd shale, which overlaps unconformably onto rocks as old as Early Ordovician. The Floyd is succeeded by the more sandy Parkwood formation, which apparently bridges the Mississippian-Pennsylvanian boundary. The Floyd and Parkwood together are broadly of the same age as, and occupy a stratigraphic position similar to, the much thicker Stanley shale and Jackfork sandstone of the Ouachita Mountains (see below), but published descriptions afford little evidence as to what extent the facies of the formations in the two regions differ from or resemble each other.[15]

[15] H. D. Miser (written communication, 1960) reported that the Parkwood formation, where examined by him, resembles the Stanley formation of parts of the Ouachita Mountains, and that it contains few or no beds resembling the Jackfork sandstone.

Mississippian strata with about the same thickness and age as those along the front of the Appalachian system extend westward on the outcrop and southwestward into the subcrop in the Black Warrior basin, where they have been penetrated in numerous wells in the gas-producing area centering around Monroe County, Mississippi (Everett, 1953; Welch, 1959). Here, many beds can be correlated with those on the outcrop, but the rocks change from dominant limestone to dominant shale, much of which is classed as Floyd shale. The lower part of the overlying sandstones probably includes equivalents of the Parkwood formation (Mellen, 1947, p. 1813; Dott and Murray, 1954, p. 6), although in some published sections they are not differentiated from the Pottsville formation (Welch, 1959).

In the Ouachita Mountains the Upper Mississippian (Meramec and Chester) is represented by the Hot Springs sandstone, Stanley shale, and Jackfork sandstone (pp. 34–37). The upper part of the underlying Arkansas novaculite includes beds of Early Mississippian age, but most of Early Mississippian time is represented by a hiatus. The Hot Springs is a thin, local deposit, but the Stanley and Jackfork extend through most of the mountain area and are as much as 20,000 feet thick. Toward the west in Oklahoma the Stanley and Jackfork wedge out before reaching the structural front of the mountains (Hendricks et al., 1947), but the abruptness of the wedging has probably been exaggerated by thrust slicing. Farther east in Arkansas the Stanley and Jackfork have been identified beneath the Atoka formation in wells drilled in the Arkansas basin as much as 30 miles north of the structural front (well 12, White County) (Maher and Lantz, 1953). The basin in which they accumulated thus had different outlines from the area which later was strongly deformed in the Ouachita Mountains.

The Stanley shale and Jackfork sandstone probably extend in subcrop south from the Ouachita Mountains for at least 25 miles beneath the Gulf Coastal Plain, beyond which they are overlapped by Eagle Mills formation and their farther extent is unknown. Here, rocks of Ouachita facies have been penetrated (including wells 42, 43, 44) which, where descriptions are available, are indurated sandstone and black shale. Rocks of this sort are reported as far east as Grant and Cleveland counties, Arkansas (Spooner, 1935, p. 334; Weeks, 1938, p. 962). They resemble the Stanley and Jackfork, and perhaps the Atoka formation. In subcrop east of the Ouachita Mountains, beneath the Mississippi embayment, the Stanley and Jackfork have not been identified, and they may be partly or wholly cut out along the strike by convergence of structural belts.

Devonian to Cambrian

Appalachian system.—In the Valley and Ridge province of the Appalachians the base of the Paleozoic sequence is quartzite and shale of Early Cambrian and Cambrian(?) age (Chilhowee group of Tennessee and Weisner formation of Alabama and Georgia). This is followed by a great carbonate sequence, nearly 9,000 feet thick, extending from the Lower Cambrian into the Lower Ordovician, and in places into the Middle Ordovician. The Rome and Conasauga formations in the lower part of the carbonate sequence include interbedded shale, but the Knox group and related units of Late Cambrian and Early Ordovician age form an uninterrupted body of limestone and dolomite. The Middle and Upper Ordovician series are thin in most of Alabama and Georgia, but they thicken in Tennessee where they contain much shale and fine-grained sandstone in the southeastern outcrop belts. The Silurian and Devonian are rather inconsequential throughout the southern Appalachians, although red iron ores of Silurian age are of economic interest in the Birmingham district, Alabama.

Subcrop extensions of Appalachian system.—Lower Paleozoic carbonate rocks like those in the Valley and Ridge province have been penetrated beneath coastal plain deposits in wells drilled southwest of the exposed Appalachian region in Greene, Marengo, and Sumter counties, west-central Alabama, and in Leake, Newton, Neshoba, and Scott counties, east-central Mississippi. The southernmost Paleozoic penetration in Mississippi is in carbonate rocks of early Paleozoic age (wells 51 and 52, Newton County). The only fossils which have been reported from wells drilled in the carbonate rocks are of Middle Ordovician and Silurian age, according to identifications by G. A. Cooper (well 55, Marengo County, Alabama; well 45, Leake County, Mississippi). However, no fossils have been observed in much of the sequence and it may be largely of Late Cambrian and Early Ordovician age; the Knox group and related carbonate rocks of these ages are poorly fossiliferous on the outcrop.

The lower Paleozoic carbonate rocks penetrated in Alabama lie on an obvious southwestward extension of those in the Appalachian Valley and Ridge province. The structural relations of the carbonate rocks penetrated in Mississippi are less certain, as they occur in a belt trending northwest parallel to the Ouachita system. They may be on the crest of an independent uplift in front of that system, but more likely they form an extension of both the subcrop belt in Alabama and the Valley and Ridge province of the outcrop (McKee et al., 1956, pl. 2). If this belt of carbonate rocks is a continuous feature, it "turns the corner" from the Appalachian trend in Alabama into the Ouachita trend in Mississippi. In central Mississippi the belt apparently wedges out, either from a westward change in stratigraphic facies or from a structural convergence of the belts on each side of it.

Ouachita system.—Cambrian to Devonian rocks emerge in the Ouachita Mountains in its central anticlinorium, as well as in outlying anticlines and fault blocks, and are described in more detail elsewhere in this publication (pp. 25–34). Briefly, they are of facies quite different from those of rocks of the same age in the Valley and Ridge province in the Appalachians, being a sequence of graptolite-bearing shales and slates, interrupted at intervals by units of sandstone and chert, mainly of Ordovician and Silurian age, which are topped by the siliceous rocks of the Arkansas novaculite, of Devonian and Early Mississippian age. Cambrian to Devonian rocks of Ouachita type are identifiable in wells in Arkansas drilled a short distance east of their outcrops in the Ouachita Mountains (well 56, Pulaski County), but they have not been recognized with certainty farther east.

Suwanee basin.[16]—In northern Florida and adjacent parts of Georgia and Alabama, Mesozoic rocks are underlain by Paleozoic rocks at depths of 2,700 to 8,000 feet below sea level (Applin, 1951, pp. 13–15). These form the Suwanee basin, a triangular area of about 25,000 square miles. The Paleozoic rocks are unmetamorphosed, dip at low angles, or lie nearly horizontal. Wells which have penetrated them are widely spaced, so that their gross structure and sequence are poorly known. They adjoin plutonic, metamorphic, and volcanic rocks of the Piedmont province of the Appalachian system on the north with an undetermined relation; they adjoin other crystalline and volcanic rocks on the south, against which they may be downfaulted. Juxtaposition of rocks of different ages or lithologies within the basin may be caused by other faults, whose pattern is as yet undetermined.

The Paleozoic rocks are probably not less than 3,000 feet thick, and may exceed 6,000 feet, but the sequence is conjectural because most wells penetrate only one lithologic unit, and no wells penetrate more than two. However, many of the well cores are fossiliferous, and contain various associations of mollusks, brachiopods, trilobites, ostracodes, and other invertebrates; graptolites have been found in one

[16] Originally named the Suwanee River basin by Braunstein (*in* Frascogna, 1957, p. 1; Braunstein, 1958a), but the shorter term seems adequate and preferable.

well but not in the remainder (Bridge and Berdan, 1951, 1952). Microscopic study has also revealed the presence in some well cores of rich assemblages of chitinozoans and plant spores (Schopf, 1959).

Sandstone probably forms the lowest unit and is at least as old as Early Ordovician; some wells have penetrated it to a thickness of more than 2,000 feet, and one well near the southeastern border of the basin (Sun Oil Company No. 1 H. N. Camp, Marion County, Florida, beyond the map area) drilled through it into an older unit of volcanic agglomerate. Most of the other strata which have been penetrated are black or dark gray shales, some with sandy laminae, which from well to well contain faunas of Early Ordovician, Middle and possibly Late Ordovician, Silurian, and Middle Devonian ages (Jean Berdan, written communication, 1960). The youngest strata may be those in Jackson County, Florida (well 62), which are red and gray sandstone and shale of fresh-water or terrestrial origin that contain plant fragments and spores of probable Middle Devonian age.

The stratigraphic and tectonic affinities of the Paleozoic rocks of the Suwanee basin are obscure. Lithologically, they are very different from the dominant carbonate rocks of the same ages in the Valley and Ridge province on the opposite side of the Appalachian system, but they somewhat resemble the slaty and sandy rocks of those ages in the Ouachita system. However, their faunas are like those of neither of these provinces nor do they agree closely with those of any other faunas in North America; some of the fossils have their nearest affinities with those in parts of Europe (Jean Berdan, written communication, 1960). Presence of Middle Devonian(?) nonmarine deposits suggests that Paleozoic deposition terminated in the Suwanee basin much earlier than it did in either the Appalachian or Ouachita basins.

The writer (King, 1950, pp. 657–658) suggested that the Suwanee basin and its Paleozoic rocks form the southeastern flank of the Appalachian system, but their relations to the Appalachian rocks and structures are uncertain; their map pattern suggests that they extend transversely across the strike of the rocks of the adjacent Piedmont province. Relations of the basin to the Ouachita system are even more remote, as the nearest proved part of that system is several hundred miles to the northwest, in Mississippi.

Weakly Metamorphosed Rocks

The rocks shown in this category on the geologic map (Pl. 3) are so classed mainly because of their metamorphic and structural character, rather than because of their stratigraphic position or age. Those in the Appalachian system include rocks of both late Precambrian and Paleozoic ages; the age of those in the Ouachita system is undetermined but is probably Paleozoic. All these rocks share a weak to moderate metamorphism and are thus intermediate in character between the unmetamorphosed rocks of the forward parts of the Appalachian and Ouachita systems and the thoroughly metamorphosed and plutonized inner parts.

Appalachian system.—In the Appalachian system weakly metamorphosed rocks form the Ocoee and Talladega belts, lying between the unmetamorphosed Paleozoic rocks of the Valley and Ridge province and the metamorphosed rocks of the Piedmont province. The Ocoee belt is in the Blue Ridge province, but this province ends as a physiographic feature in northwestern Georgia, so that the Talladega belt farther southwest is physiographically part of the Piedmont province.

The rocks of both the Ocoee and Talladega belts form a separate thrust slice or slices, which are faulted over the Paleozoic rocks of the Valley and Ridge province along a discontinuity known in the north as the Great Smoky fault and farther south as the Cartersville fault. The more metamorphosed rocks of the Piedmont province are in turn faulted over the weakly metamorphosed rocks along the Whitestone fault on the southeast side of the Ocoee belt, and along a fault which follows the Hillabee sill along the southeast side of the Talladega belt.

The Ocoee belt, from Cartersville, Georgia, north into Tennessee and North Carolina, is formed mainly of the Ocoee series, a mass of fine to coarse clastic rocks more than 30,000 feet thick (P. B. King et al., 1958, pp. 949–951). Along the northwest side of the belt the series lies in stratigraphic sequence beneath fossiliferous rocks of Early Cambrian age, hence the Ocoee itself is probably of late Precambrian age. The rocks of the Murphy belt, which borders the Ocoee belt on the southeast, may be equivalent to rocks of proved Cambrian age northwest of the Ocoee belt, but they are unfossiliferous. In western North Carolina, in the extreme northeast corner of the map area, the Ocoee series lies unconformably on metamorphic and plutonic rocks of an earlier Precambrian age (pp. 93–94).

The Talladega belt extends southwestward from Cartersville, Georgia, across Alabama to the edge of the Gulf Coastal Plain and has been described by Griffin (1951, pp. 28–48), Butts (1926, pp. 49–61), and earlier authors. Parts of the belt in Alabama were examined in reconnaissance in the spring of 1961 by the writer, R. B. Neuman, and R. A. Laurence, and their observations largely confirm the published accounts.

In Alabama the rocks of the Talladega belt form a southeast-dipping sequence whose thickness Butts estimates to be about 30,000 feet. Earlier accounts have suggested that the belt contains equivalents of the Precambrian Ocoee series farther northeast, but if present these are minor. The greater part of the sequence is probably of Paleozoic age, although the rocks are more metamorphosed and are of a more clastic facies than the Paleozoic rocks in the Valley and Ridge province which adjoin them on the northwest. The lower part of the sequence is a great body of slates and phyllites, in part tuffaceous and containing rare limestone lenses, which is probably of early Paleozoic age. East of Birmingham this body is followed by the persistent, ridge-forming Cheaha sandstone, from which crinoid stems have been reported and which is probably of middle Paleozoic age; its equivalent south of Birmingham may be the Butting Ram sandstone. The Butting Ram south of Birmingham is overlain by the Jemison chert which contains brachiopods of Devonian age. The Cheaha east of Birmingham is overlain by the Erin slate which contains fossil plants, reported to be of Pennsylvanian age. Pennsylvanian or other later Paleozoic rocks may be preserved elsewhere in the belt; in cuts on the new Birmingham-Montgomery freeway, near the edge of the coastal plain south of Jemison, King, Neuman, and Laurence observed sandstone and carbonaceous shale with interbedded sheared coal; fossil bryozoans have been reported in these rocks by local collectors.

The sequence of weakly metamorphosed Paleozoic rocks of the Talladega belt is of interest in the present discussion, because it might be an Appalachian analogue of the sequence of Paleozoic rocks in the Ouachita Mountains. Both sequences approach a eugeosynclinal facies and are dominantly clastic, but from what is pressently known the succession of units in the Talladega belt is not notably like that in the Ouachita Mountains.

The rocks of the Talladega belt in the Appalachian system extend southwestward into subcrop beneath the Gulf Coastal Plain but have not there been identified; however, well control is very sparse where they might occur. On the geologic map (Pl. 3), their subcrop extension is indicated theoretically.

Ouachita system.—Very weakly to weakly metamorphosed rocks of unknown but probable Paleozoic age have been penetrated in half a dozen wells in a belt extending through Arkansas County, Arkansas, and Bolivar County, Mississippi, to Attala County, central Mississippi. Detailed reports are available on the rocks penetrated in only a few of these wells, the remainder being reported as of "Ouachita" facies. In one well in Carroll County (well 71), according to Weaver (p. 159 and fig. 7), the sharpness ratio of the clays exceeds 5.0, "which is within the range of values of low-grade metamorphism." Two wells in Attala County to the south (wells 72 and 73) penetrated black slates, siliceous slates, and cherts that have undergone weak to low-grade metamorphism and contain much chlorite and sericite but the sharpness ratio of their clays is less (fig. 7). Except for a few sponge spicules in the siliceous rocks, no fossils have been observed, but the general aspect of the rocks is like that of the older Paleozoic formations of the Ouachita system farther west.

These very weakly to weakly metamorphosed rocks may lie on an extension of the central anticlinorium of the Ouachita Mountains to the west as suggested on the map (Pl. 3), or they may be parts of thrust slices of the inner zones of the Ouachita system. North of the Ouachita Mountains a wide band of Mississippian Stanley shale and Jackfork sandstone intervenes between the older Paleozoic rocks of the anticlinorium and the deformed Pennsylvanian rocks of the Arkansas basin; here the rocks are strongly folded, but available evidence suggests that faulting is minor. By contrast, in central Mississippi the weakly metamorphosed rocks appear to be juxtaposed against deformed Pennsylvanian rocks, suggesting an elimination of some of the structural belts of the outcrop area, probably by thrust slicing.

The extent of the weakly metamorphosed rocks farther south in the Gulf Coastal Plain is undetermined, as in this direction the pre-Mesozoic basement is generally beyond reach of drilling. In Cleveland County, Spooner (1935, pp. 392–394) reported a penetration of shale, limestone, and possibly chert, intruded and metamorphosed by peridotite. Two wells in the Smackover oil field of southern Arkansas (wells 74, 75) are reported to have entered argillaceous rocks beneath the Jurassic(?) Werner formation, intruded and altered by diabase. The affinities of these rocks to those farther north is uncertain, and their metamorphism may result from proximity to the mafic intrusions.

Metamorphic and Plutonic Rocks

This unit is shown on the geologic map only in the Piedmont province of the Appalachian system and in its subcrop extensions to the southeast and southwest. The rocks so mapped share an extreme metamorphism and plutonism but are heterogeneous in detail, both in lithology and degree of metamorphism (Crickmay, 1952, pp. 50–52; P. B. King, 1955a, pp. 343–363).

Extensive areas are formed of monotonous bodies of gneiss and schist, commonly termed "Carolina gneiss" in early reports, but in places there are beds or units of quartzite and marble, and on the southeast side of the belt (mainly in the Carolina slate belt, northeast of the map area) are extensive bodies of volcanic rocks and associated slates. The rocks of the Wacoochee belt, near the southeast edge of the exposures in the Piedmont province of Alabama and Georgia, include the thick, persistent Hollis quartzite and the overlying Chewacla marble (Hewett and Crickmay, 1937, pp. 26–30). Embedded in the metamorphic rocks are pods and plutons of all sizes, composed of felsic plutonic rocks, varying from foliated to massive. In places, mainly northeast of the map area, are plutons of more mafic rocks.

In the Blue Ridge province in the extreme northeast part of the map area, between the Ocoee belt and the Brevard belt, the metamorphic and plutonic rocks are known to be unconformable beneath the Ocoee series (P. B. King et al., 1958, p. 963), hence to be of an earlier Precambrian age; this is confirmed by a few radiometric determinations. Elsewhere in the Piedmont province, mainly southeast of the Brevard belt, the age of the metamorphic rocks is less certain. They may be partly or wholly of Paleozoic age, although no fossils have been found in them. The plutonic rocks which invade them have been dated radiometrically as between 400 and 250 million years, hence are of early to middle Paleozoic age. No radiometric dates of either Precambrian or late Paleozoic age have been reported from the Piedmont province southeast of the Brevard belt.

The gross structure of the metamorphic and plutonic rocks is little known and is probably complex. In many areas the foliation in the gneiss and schist dips rather gently, and the latest structures imposed on them may have been open anticlinoria and synclinoria. In places, however, are zones of intense shearing and cataclasis. The narrow Brevard belt crosses the province with a nearly straight or gently curved trend and must be a major structural element; its true nature has not been proved, but extensive strike-slip movements may have occurred along it.[17]

Metamorphic and plutonic rocks like those in the exposed parts of the Piedmont province have been penetrated by wells drilled through the coastal plain deposits in parts of southern Georgia and Alabama (wells 76–88; see also Applin, 1951, pp. 5–11). The rocks are variously described as schist, gneiss, and granite, but the wells are not spaced closely enough to determine details of the bedrock pattern.

In southeastern Georgia along the north side of the Suwanee basin a well in Atkinson County (well 88) and another to the east in Camden County penetrated altered rhyolitic volcanic rocks (Applin, 1951, pp. 8–11). These rocks are comparable to those penetrated in half a dozen or more wells on the south side of the Suwanee basin in central Florida. These rhyolitic volcanic rocks differ greatly from the Triassic mafic igneous rocks of the same area, and their alteration suggests that they are much older. They may underlie the Paleozoic sedimentary rocks of the Suwanee basin, as in one well in central Florida they are overlain by quartzitic sandstone of probable Ordovician age (Applin, 1951, p. 14). They are perhaps related to volcanic rocks of the Carolina slate belt in the exposed Piedmont province. The age of the latter is unknown but is generally believed to be of some undetermined part of the Paleozoic.

GEOPHYSICAL DATA[18]

Geophysical data on the eastern part of the Gulf Coastal Plain supplement the well data and extend the structural picture downward beyond limits of control by drilling. However, results of many past geophysical investigations are unpublished, and results of other investigations now in progress are not yet available. Woollard (1949, 1958) has summarized some of the results of gravity and seismological studies, and Lyons (1950) has published a gravity map of the United States which includes significant information on the region here treated. Results of a more detailed magnetic survey of Florida have been presented by E. R. King (1959).

In the eastern United States, gravity maps show a weak positive anomaly (less than plus 20 milligals) along the axes of the Cincinnati and Nashville domes, a strong negative anomaly in the Blue Ridge province of the Appalachians (more than minus 100 milligals in northwestern North Carolina), and prevailing positive anomalies in the Piedmont province (plus 20 to 40 milligals from North Carolina to New England). Southwestward, within the area here treated (fig. 4), the negative anomalies of the Blue Ridge province are concentrated near the Brevard belt, suggesting a fundamental and deep-seated origin for that structure. Northwest of it, in the Blue Ridge and Valley and Ridge provinces,

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[17] Further details on probable strike-slip displacements along the Brevard belt are given in a manuscript now in preparation by J. C. Reed, Jr., H. S. Johnson, Jr., Bruce Bryant, and W. C. Overstreet, of the U. S. Geological Survey. These authors record a prominent horizontal linear structure in the metamorphic rocks of the belt in North and South Carolina.

[18] In preparation of this discussion the writer is indebted to Isidore Zeitz, Martin Kane, Andrew Griscom, H. R. Joesting, and E. R. King, geophysicists of the U. S. Geological Survey, who have made many helpful suggestions. However, the opinions expressed herein are solely those of the writer.

gravity trends extend diagonally across the trends of the surface structures, confirming the superficial nature of the deformation in those provinces that has been deduced from geological evidence.

In the south-central United States gravity maps show well-marked positive anomalies (as much as plus 40 milligals) along the axes of the Wichita, Arbuckle, and related uplifts, reflecting the presence of basement rocks at or near the surface. By contrast, the salient of the Ouachita Mountains which centers in southeastern Oklahoma shows a major negative anomaly (more than minus 100 milligals).

These belts of strong positive and negative gravity disappear in the Atlantic and Gulf Coastal Plains and Mississippi embayment, where there are weaker and less well-defined positive and negative areas, some of regional extent, but none showing clear relations to the trends of either the Appalachian or Ouachita systems. In places the change in gravity pattern along the edge of the coastal plain is abrupt, resulting in steep gradients such as those at the edge of the Mississippi embayment in the southeastern part of the Ouachita Mountains of Arkansas and at the southwest end of the exposed Brevard belt in Alabama. The trends of earthquake epicenters associated with the Appalachian system likewise disappear near the edge of the coastal plain (Woollard, 1958, p. 1149). Of more obvious origin than the larger gravity features in the coastal plain are small areas of positive gravity anomaly. Those at Jackson, Mississippi, and south of Little Rock, Arkansas, coincide with intrusive bodies in the Mesozoic or older rocks. Others in southern Alabama and Georgia probably have a similar origin.

In northern Florida near the Suwanee basin narrow but pronounced gravity and magnetic belts trend northeastward (E. R. King, 1959, pp. 2852–2853), reflecting either a grain in the basement parallel to that in the Piedmont province of the Appalachian system, fault blocks in the Paleozoic and basement rocks of the basin, or both. In southern Florida these belts terminate against a northwest-trending gravity and magnetic grain. This grain may be related to a southeastward prolongation of the Ouachita system and to a southwestward truncation of the Appalachian system as suggested by E. R. King (1959, pp. 2852–2853), but it coincides in position with the pronounced southwestward thickening of Mesozoic and younger rocks in southern Florida.

Meaning of the gravity, magnetic, and seismic patterns of the region remains elusive. The large negative gravity anomalies (more than minus 100 milligals) in the Appalachian and Ouachita areas indicate the presence of rock masses of less than normal density. In part at least, these are bodies of sedimentary rocks that were originally thick and that have been further thickened tectonically, as in the Ocoee belt and the belt of Stanley, Jackfork, and Atoka formations. However, the magnitude of the anomalies would require masses of rock of less than normal density that are 25,000 to more than 100,000 feet thick (Martin Kane, written communication, 1960), so that the density difference must also extend into the basement and into the crust.

Disappearance of the well-marked positive and negative trends of the Appalachian and Ouachita systems in the coastal plain area is paradoxical, as drill data indicate that both systems extend unchanged for long distances beneath the coastal plain cover. A geologist is tempted to suspect that this cover in some manner exerts a damping effect on the geophysical manifestations of the underlying rocks; however, for negative anomalies of the magnitude of those in the Appalachian and Ouachita systems this would require a cover much thicker than 10,000 feet (Martin Kane, written communication, 1960). Geophysical considerations thus suggest a notable difference in the nature of the crust between that in the exposed Appalachian and Ouachita systems and that of the coastal plain area.

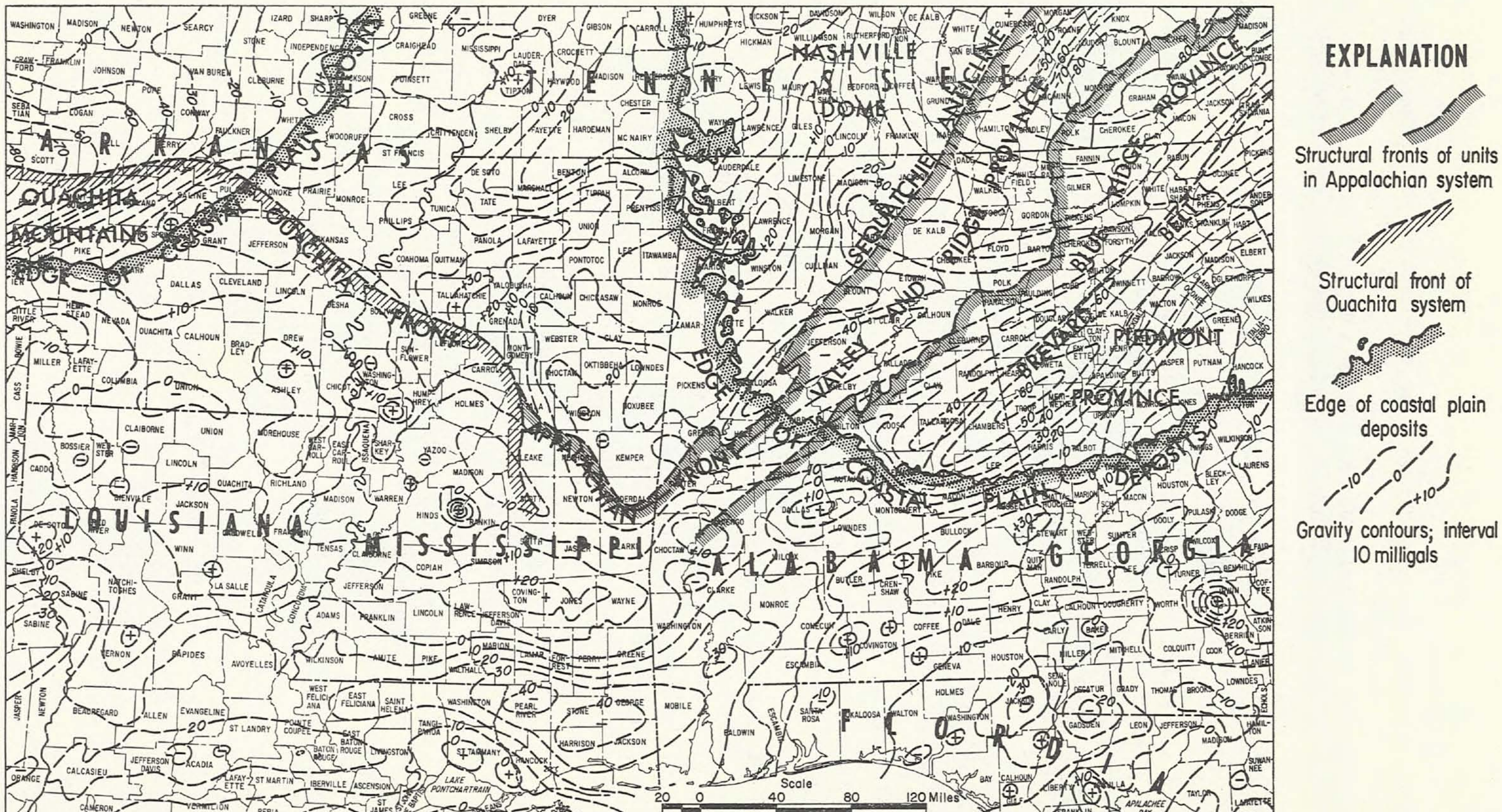

FIG. 4. Gravity map showing Bouguer anomaly of part of southeastern United States.

RELATIONS BETWEEN OUACHITA AND APPALACHIAN SYSTEMS

Evidence and inferences so far presented contribute to a solution of the problem of the relations between the Ouachita and Appalachian systems but are insufficient to solve it, as data are still lacking in many critical areas. Nevertheless, some suggestions can be made.

The Ouachita and Appalachian systems are now interrupted by a cover of younger coastal plain deposits, but there is little doubt that they are parts of an originally continuous belt of deformation, whatever the precise nature of their junction. The writer believes that the Appalachian system is too broad and massive a structure to terminate abruptly southwestward, despite its poor geophysical expression in the coastal plain area. The magnitude of the less completely exposed Ouachita system is not as obvious, but many considerations suggest it is equally broad and massive.

These inferences seem to be confirmed by available drill data in the coastal plain area. Sediments laid down on the foreland during the deformational epoch are continuous from one system to the other. Both the Mississippian and Pennsylvanian systems thicken and become more clastic, not only southeastward toward the Appalachian system and southwestward toward the Ouachita system but also southward into the intervening Black Warrior basin.

So far as they can be traced, structural belts of the Ouachita and Appalachian systems are continuous beneath the coastal plain cover, being most accordant in the foreland area and increasingly discordant toward the inner parts of the systems. The Mississippian outcrop and subcrop belt, well out in the foreland, pursues a gentle curve from the strike of one system to that of the other. The Pennsylvanian outcrop and subcrop belt along the edge of the systems forms a sharper curve from the strike of one to that of the other and expands at the angle between them into the triangular Black Warrior basin. The belt of lower Paleozoic carbonate rocks extends westward from the Valley and Ridge province of the Appalachians into a belt parallel with the Ouachita system in east-central Mississippi but bends at nearly right angles in passing from the trend of one system to that of the other. If any connection exists between the belts of weakly metamorphosed rocks farther southeast and southwest in the two systems, their junction must be at an even more acute angle.

The writer (King, 1950, p. 668) suggested that the inner, eugeosynclinal, weakly metamorphic and metamorphic belts of the Appalachian system continue westward into the outer belt of the Ouachita system, curving from one trend to another, and eliminating by thrusting the outer miogeosynclinal belt as they do so. Alternatively, E. R. King (1959, p. 2853) has suggested on the basis of geophysical evidence that the Ouachita belt may cut off transversely the southwest end of the Appalachian belt and continue independently into southern Florida.

Both suggestions are probably oversimplifications. A more fruitful possibility has been suggested by Woollard (1949, p. 1932), that the junction is comparable to those of island arcs and deep trenches at sea, which may be mobile belts in an early stage of development. From what is known of the island arcs and trenches, their intersections are most complex, with the two trends crossing each other but neither extending far beyond their intersection. Very likely a similarly complex intersection occurs between the inner parts of the Ouachita and Appalachian systems, in the deeply buried area in southern Mississippi and Alabama.

The inner part of the Ouachita system differs from the inner part of the Appalachian system in its post-orogenic history. It has been strongly susceptible to subsidence and has been deeply covered by younger coastal plain deposits, whereas the inner part of the Appalachian system is still partly exposed and at most is covered by thin younger deposits. West of the Mississippi River the edge of the area of deep subsidence corresponds closely to the edge of the inner zone of the Ouachita system. East of the Mississippi River the edge of the area of deep subsidence extends southeastward, beyond the point where the Ouachita and Appalachian systems should intersect, at least as far as southern Florida (E. R. King, 1959, p. 2848).

Gravity data suggest a fundamental difference between the crustal material beneath the Gulf Coastal Plain, especially in the area of deep subsidence, and that in the Appalachian area. Passage from the characteristic features of the Appalachian system to those of the Ouachita system may result more from such a change in crustal material than from a structural truncation.

During the orogenic phase the metamorphic rocks of the Piedmont province of the Appalachians were extensively granitized and were pervasively injected by felsic plutonic bodies. A similar history has been inferred by Flawn (p. 105) for the inner part of the Ouachita system far to the west, beyond the Gulf Coastal Plain in northeastern Mexico. Less is known of the metamorphic and plutonic history of the inner part of the Ouachita system in the intervening area, where it has subsided deeply beneath coastal plain deposits. Possibly this part was less pervasively injected by felsic plutonic bodies and was less completely converted to sialic crust than the parts to the east and west.

An extreme alternative, still not to be dismissed, was suggested nearly 30 years ago by Van der Gracht (1931a, pp. 1409–1051)—that the original felsic or sialic inner part of the Ouachita system has broken away by drift during a post-orogenic distention of the Gulf and Caribbean areas. This inner part, and perhaps also the original junction of the Appalachian and Ouachita systems, may thus now be found somewhere in Central America or northern South America. The area of supposed great subsidence of the inner part of the Ouachita system in the Gulf Coastal Plain would instead be the void produced by drift, over whose simatic floor sediments were prograded to the present edge of the continental shelf during Mesozoic and Cenozoic time.

The Ouachita Structural Belt in Mexico

PETER T. FLAWN

General remarks.—The rocks and structures of the frontal zone of the Ouachita belt exposed in the Solitario uplift of Trans-Pecos Texas are only 15 miles from the Rio Grande and they strike southwest toward it. From the trend of the Ouachita belt as mapped in Texas (Pl. 2) and from scattered outcrops and wells in northern Mexico, the Ouachita system must extend southwestward and southward into Mexico. However, it is poorly known there because of the thick concealing cover of Cretaceous and younger rocks, complications introduced by strong Laramide deformation, paucity of well control, and general lack of information about the widely separated areas of exposed pre-Mesozoic rocks. Some of the problems of Paleozoic tectonics in Mexico have been discussed by Kellum et al. (1936), R. E. King (1944), Still (1946, 1947), Eardley (1951), P. B. King (1951), Acevedo and Marquez (1952), De Cserna (1956), De Cserna and Díaz G. (1956), and Flawn and Díaz G. (1959).

EXPOSURES OF PRE-MESOZOIC ROCKS IN NORTHERN MEXICO

Outcrops of pre-Mesozoic rocks in Chihuahua, Coahuila, Nuevo Leon, Tamaulipas, northern Zacatecas, and northern San Luis Potosi are shown on figure 5. Undoubtedly, additional exposures of pre-Mesozoic rocks will be discovered with further geologic mapping.

Sierra del Carmen.—Outcrops of pre-Mesozoic metamorphic rocks in the Sierra del Carmen near Boquillas, Coahuila, were discovered by C. L. Baker (Böse, 1923, p.
133 ~~113~~; Baker, 1935, p. 146) and have been described by Flawn and Maxwell (1958).

The metamorphic rocks are thinly interlayered very fine-grained graphitic chloritic sericite schist (or phyllite), fine-grained calcite marble, and fine-grained metaquartzite with gradational types including calcareous schist, schistose or phyllitic marble, and phyllitic metaquartzite. All have been subjected to low-grade metamorphism with a high shearing component. Early quartz veins have been sheared, broken, and drawn out into knots or augen; post-shearing quartz veins cut across earlier structures. The rocks are foliated, and commonly the foliation is crinkled and contorted. Determinations of the age of the mica are inconclusive and yielded divergent ages of 240 and 370 million years (George Edwards, Shell Development Company, personal communication, 1959). The results suggest that the metamorphism occurred during Paleozoic time but do not date the rocks themselves. The rocks are like those encountered in wells in southwest Texas, in Kinney, Val Verde, and Terrell counties. The original sequence may have been thin-bedded impure dark shale and limestone similar to the Marathon formation in the Marathon and Solitario uplifts to the north. Probably these rocks are early Paleozoic in age (p. 81).

The exposure in the Sierra del Carmen is the only known outcrop of the interior zone of the Ouachita belt (p. 169 and Pl. 2).

Sierra del Cuervo.—Paleozoic exposures in the Sierra del Cuervo, about 18 miles north of the City of Chihuahua, have been described by Acevedo and Marquez (1952), De Cserna and Díaz G. (1956, p. 47), and Flawn and Díaz G. (1959).

Paleozoic rocks in the Sierra del Cuervo are interbedded sandstone and slaty shale containing sporadic limestone lenses. These are strongly deformed, highly sheared, and very weakly to weakly metamorphosed with incipient foliation and local well-developed lineation. The rocks

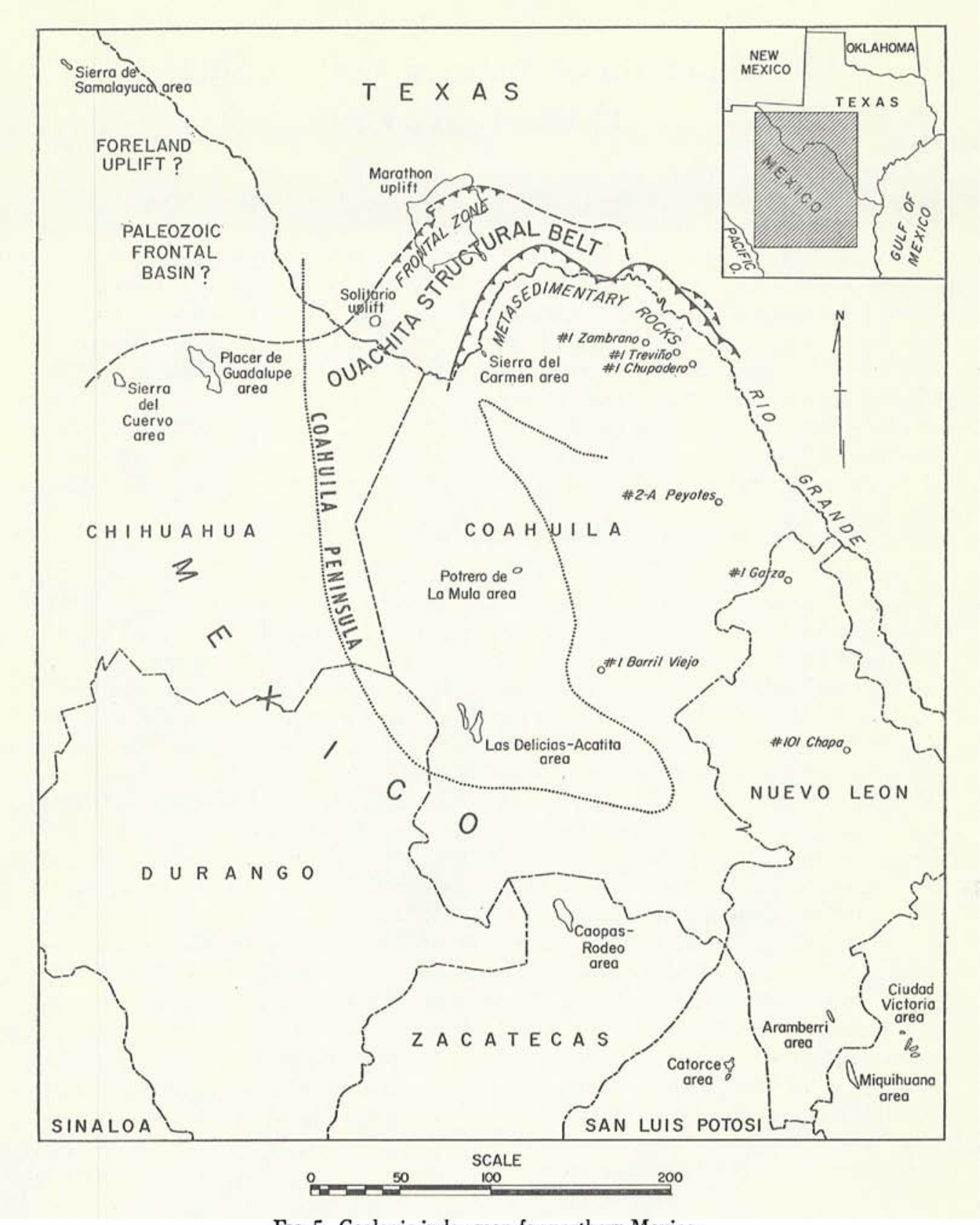

FIG. 5. Geologic index map for northern Mexico.

may be as much as 3,300 feet thick. Wolfcamp fusulinids have been identified from near the top of the sequence by J. W. Skinner (Flawn and Díaz G., 1959, Table 1). The rocks are probably Upper Pennsylvanian (?) and Lower Permian.

The Paleozoic rocks of the Sierra del Cuervo are a late Paleozoic orogenic (flysch) facies. When the post-Paleozoic deformation is subtracted, the Paleozoic structures show a northeast-southwest strike nearly parallel to the strike of Paleozoic structures in the Solitario uplift and Marathon Basin in Texas (Ernst Cloos, *in* Log of Cd. Chihuahua to Sierra del Cuervo field trip, Int. Geol. Cong. XX, Excursion A-13, and Teodoro Díaz G., personal communication, 1958).

Placer de Guadalupe area.—Paleozoic rocks crop out near Placer de Guadalupe about 60 miles northeast of the city of Chihuahua and have been described by King and Adkins (1946), Still (1946, 1947), De Cserna and Díaz G. (1956, pp. 37–39), and Flawn and Díaz G. (1959). Luther W. Bridges is currently studying the area as part of a doctoral dissertation problem at The University of Texas; preliminary results of this study have been reported (Bridges and DeFord, 1961).

Paleozoic rocks exposed in the area of Placer de Guadalupe include about 4,000 feet of Ordovician, Silurian(?), Devonian, Mississippian, Pennsylvanian, and Permian strata. Most of the sequence is composed of shaly and cherty limestone, locally fossiliferous, of shelf or platform facies. The pre-Carboniferous rocks aggregate about 1,800 feet in thickness. In the upper part of the sequence there is about 1,600 feet of Permian(?) rock consisting of dolomitic pisolitic reef(?) limestone containing Wolfcamp fossils and overlain by nonfossiliferous siltstone and conglomerate. Thus, the youngest Paleozoic rocks in the area are Wolfcamp or possibly Leonard in age.

The rocks have undergone both pre-Mesozoic and Laramide deformation and hence are much folded. According to Bridges and DeFord (1961, p. 103) ". . . regional metamorphism has not proceeded farther than recrystallization of the limestone." Analysis of the pre-Mesozoic structure suggests that these rocks are within or close to the northwestern margin of the Ouachita structural belt.

Las Delicias-Acatita area.—The Las Delicias-Acatita area, located in southwestern Coahuila 60 miles north-northwest of Torreon, has been described by Haarmann (1913), Böse (1921), R. E. King (1934), Kellum et al. (1936), Kelly (1936), R. E. King et al. (1944), Humphrey (1955), and Newell (1957); the significance of these exposures in relation to regional structure has been discussed by the original geologists in the area (above) and by P. B. King (1951), Eardley (1951), De Cserna (1956), and Flawn and Díaz G. (1959).

The Paleozoic sequence in the area is as much as 12,000 feet of interlayered sedimentary and volcanic rocks including phyllite, slate, shale, quartzite, sandstone, graywacke conglomerate, fossiliferous limestone, lava, and tuff; the sedimentary rocks are steeply folded and intruded by granite and granodiorite. Degree of metamorphism varies in different parts of the area, ranging from incipient to weak with hornfels developed locally as a contact phenomenon. The sedimentary rocks range from Late Pennsylvanian(?) to Permian in age and include beds of Wolfcamp(?), Leonard, Guadalupe, and Ochoa(?) age, although Leonard and Guadalupe beds make up most of the section and are much thicker than comparable sequences in Texas; the facies is geosynclinal. The granite is either Late Permian or post-Permian and pre-Cretaceous (Albian) in age.

Caopas-Rodeo area.—About midway between Parras, Coahuila, and Gruñidora, Zacatecas, pre-Mesozoic rocks are exposed in the core of a northwest-trending fold. This area is briefly discussed by De Cserna (1956, pp. 13–14 and map) who credits C. L. Rogers and others (in preparation) with the original work.

There is an older sequence of mica schist with thin beds of quartzite and conglomerate (Caopas series) and a younger sequence of interlayered phyllite and altered volcanic rocks (Rodeo formation). The Rodeo is unconformably overlain by Mesozoic rocks of the Huizachal group. The Caopas series and Rodeo formation are tentatively considered to be Permo-Carboniferous (Rogers et al., in preparation).

The weakly metamorphosed sedimentary and volcanic rocks in this area may be part of the Paleozoic orogenic terrane.

Galeana area.—About 98 highway miles south and west of Saltillo and 7 or 8 miles from the town of Galeana (near San Pablo), Nuevo Leon, road cuts expose jointed and faulted sandstone (graywacke) intruded by small bodies of fine-grained igneous rock and apparently in fault contact with gypsum of pre-Oxfordian age. These rocks may be Paleozoic or they may be part of the Triassic La Boca formation (R. B. Mixon, personal communication, 1959).

Sierra de Catorce.—Baker (1921, 1922) described metamorphic rocks in the Sierra de Catorce in northern San Luis Potosí as an older series of sericitic and talcose schists and volcanic rocks and a less metamorphosed series of sandy, shaly, and possibly tuffaceous rocks interbedded with conglomeratic quartzites; both are transversed by quartz veins. De Cserna (1956, p. 13) believed that these rocks are upper Paleozoic.

Cd. Victoria area.—Pre-Mesozoic rocks are exposed in three areas northwest and west of Cd. Victoria in central and western Tamaulipas. Immediately west and northwest of the city the frontal fold of the Sierra Madre Oriental has been breached by Novillo, Peregrina (La Presa), Caballeros, and La Boca canyons, exposing crystalline rocks, probably Precambrian in age, and Paleozoic rocks. The pre-Mesozoic rocks of this area have been discussed by Baker (1921, 1936), Girty (1926), Muir (1936), Heim (1940), P. B. King (1951), Humphrey and Díaz G. (1953), Bodenlos et al. (1956, p. 63), Chandler (1957), and Flawn and Díaz G. (1959). Although there are many different kinds of crystalline rocks in the area, preliminary reconnaissance suggests there are two main groups: (1) massive light-colored garnetiferous gneiss and (2) dark mica schist, locally graphitic. Strongly deformed slightly metamorphosed Paleozoic rocks are faulted against the crystalline rocks in a number of fault blocks. For many years it has been known that a thick sequence of interlayered dark shale and sandstone of orogenic (flysch) facies containing Mississippian fossils at the bottom and Permian (Leonard) fossils in the upper part occurs in Peregrina Canyon. Recently, José Carrillo B. of Petroleos Mexicanos has discovered in Caballeros Canyon[19] Silurian and Devonian rocks and older sedimentary rocks that are probably Ordovician. Silurian and Devonian rocks are dark siltstone, black shale (containing graptolites), light-colored chert or novaculite, and dark thin-bedded fossiliferous limestone. Although the sequence is still little known and no generalizations can be made, the rocks have many of the characteristics of Ouachita facies rocks or transitional rocks. The more or less unaltered Silurian and possibly Ordovician rocks indicate that the crystalline rocks are probably Precambrian.

Southwest of Cd. Victoria at Miquihuana, Baker (1921) reported green talcose and sericitic schists extensively crumpled and cut by quartz veins. Imlay (1944, p. 1142) also reported talcose schists in this area. De Cserna (1956, p. 13) reported a discovery by R. R. Alexandri of phyllites of probable upper Paleozoic age northwest of Cd. Victoria near Aramberri.

Potrero de La Mula area.—Granitic rocks are exposed in the Potrero de La Mula in east-central Coahuila. These rocks have been discussed by Tappolet (1928), Kellum et al. (1936), and Flawn and Díaz G. (1959). Kellum et al. and Humphrey (in manuscript) concluded that these rocks are pre-Cretaceous; Tappolet and Díaz G. interpreted them as post-Cretaceous. Final resolution of the question will require detailed field mapping.

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[19] Determinations on fossils collected by José Carrillo B. of Petroleos Mexicanos were made by W. C. Bell, J. L. Wilson, Otto Majewske, and Thomas Amsden (trilobites and brachiopods), and W. B. N. Berry (graptolites). His report on this area has recently been published (Carillo B., José (1961) Geología del anticlinoria Huizachal-Peregrina al N-W de Ciudad Victoria, Tamps.: Asociación Mexicana de Geológos Petroleros, Bol. Vol. XIII, no. 1 y 2, pp. 1–98.

WELLS PENETRATING PRE-MESOZOIC ROCKS IN NORTHERN MEXICO

Three wells have penetrated pre-Mesozoic rocks in northern Mexico (fig. 5):

1. No. 2-A Peyotes (82.5 km. S. 22° W. from Eagle Pass, Texas) in northeastern Coahuila.

2. No. 101 Chapa (11,750 m. S. 77°09′ E. of Cerralvo) in north-central Nuevo Leon.

3. No. 1 Barril Viejo (also known as No. 2 San Marcos) (45 km. S. 59° W. from Monclova) in south-central Coahuila.

The No. 2-A Peyotes (p. 345) encountered very fine-grained sericite-muscovite schist and sericitic metaquartzite; metamorphism is low grade with a high shearing component. These rocks are similar in lithology and type of metamorphism to those exposed in the Sierra del Carmen and encountered in numerous wells in Kinney, Val Verde, and Terrell counties north of the Rio Grande. The No. 101 Chapa (p. 345) penetrated dark sericite-chlorite slate and dark, fine- to medium-grained, angular, poorly sorted, chloritic micaceous feldspathic metasandstone (metagraywacke) containing abundant fragments of slate-phyllite, chert, and quartz mosaic; metamorphism is weak. These rocks are of geosynclinal facies and are similar to those penetrated in the interior part of the frontal zone of the Ouachita belt in central Texas. From a study of the samples, the No. 1 Barril Viejo (reportedly bottomed in arkose) appears to have penetrated granitic rocks *in situ.*

ANALYSIS OF OUTCROP AND WELL DATA

There are two widely separated areas in northeastern Mexico where strongly deformed and highly sheared late Paleozoic flysch-type orogenic sedimentary rocks are exposed—in the Sierra del Cuervo and Placer de Guadalupe areas in Chihuahua and in the Cd. Victoria area of Tamaulipas. In the Sierra del Cuervo, Wolfcamp fossils occur in limestone lenses in the upper part of the sequence; the rocks near Cd. Victoria have not been adequately studied, but in Peregrina Canyon Mississippian fossils occur in sandstones in the lower part of the section along the contact with the crystalline rocks, and Permian fossils (Leonard) occur higher up in a very strongly deformed sequence. At least part of this flysch is thus Early Permian in age. Strongly deformed rocks of Permian age but of different facies occur in the northern part of the Placer de Guadalupe area and in the Las Delicias-Acatita area; in these areas no flysch has been described. A thick sequence of volcanic rocks, graywacke, and dark shale in the Las Delicias-Acatita area suggests that these sedimentary rocks are of eugeosynclinal facies. In the northern part of the Placer de Guadalupe area, on the other hand, the rocks are of foreland facies.

It is tempting to connect the south- or southwestward-striking Ouachita structural belt as exposed in the Marathon and Solitario uplifts in Texas and known outcrops of Paleozoic rocks of geosynclinal facies in northern Mexico, but such correlations are hazardous at present. Kellum et al. (1936), R. E. King (1944), Eardley (1951), and P. B. King (1951) have discussed the possibility that the Ouachita belt strikes south and includes the Pennsylvanian(?) and Permian rocks of the Las Delicias-Acatita area. Another possibility is that the Ouachita structures strike southwestward into Mexico and that the front of the belt passes north of the Placer de Guadalupe and Sierra del Cuervo areas, thence turning sharply south toward the Las Delicias-Acatita area (Díaz G., 1956, pp. 9–14).[20] Still another possibility, suggested by R. K. DeFord (personal communication, 1958), is that the Paleozoic folds are offset by a post-Paleozoic strike-slip fault tending northwest-southeast in the approximate position of the Rio Grande trench and that the southwest side has moved northwest.

The exposed orogenic facies Paleozoic rocks in northern Mexico include Permian and possibly Pennsylvanian rocks as well as Mississippian rocks near Cd. Victoria; the deformation is known to be post-Leonard in the Cd. Victoria area and post-Wolfcamp in the Sierra del Cuervo; in the Las Delicias-Acatita area, Guadalupe and possibly Ochoa equivalents are deformed. The final orogenic phase in Mexico thus took place in very late Permian time, as compared with the Late Pennsylvanian and possible early Wolfcamp orogeny in the Marathon area.

The fundamental Mesozoic feature of northern Mexico was the Coahuila peninsula (Kellum et al., 1936), a relatively stable block or platform defined by (1) absence of Jurassic and Triassic sedimentary rocks and (2) more intense Laramide folding and thrust faulting along the south and west borders. Kellum et al. (1936, pp. 977–978) described the Coahuila peninsula as the foreland of the Mexican geosyncline:

> (1) In the south this landmass was formed by marine Permian sediments and lavas, by Permian or post-Permian intrusive granites and granodiorites, and by a series of phyllites, quartzites, slates, shales, and conglomerates of Paleozoic age, probably in part Permian; (2) in central Coahuila it is composed of granitic rocks and associated dikes and quartz veins; and (3) in northern Coahuila it is composed of pre-Cambrian mica schist. The Permian sediments of southern Coahuila are believed by Böse, King, and Kelly to have been deposited in the same geosyncline as

[20] Díaz G. originally suggested that the orogenic front passed south of the Placer de Guadalupe area, but Bridges' work (p. 101) shows that the Placer de Guadalupe area was affected by the Paleozoic folding.

those of western Texas. The mica schists of Sierra del Carmen, and possibly the granitic rocks of Potrero de La Mula, were part of the land area that existed adjacent to this earlier geosyncline.

Thus, Kellum et al. (1936) believed that the Coahuila block was an uplift of the Paleozoic deformed belt and an "adjacent land area." In the last two decades, data have become available which permit a clarification of earlier ideas.

There is considerable evidence to indicate a major pre-Mesozoic granitic terrane in northern Mexico lying on the east side of the Coahuila peninsula. There are granitic outcrops at Potrero de La Mula; granodiorite was encountered in the No. 1 Barril Viejo; thick Jurassic (and Triassic?) arkosic sequences are present in eastern Coahuila and have been penetrated in wells in Coahuila and Nuevo Leon;[21] D. N. Miller (1955) deduced a northern Mexico granitic source for late Permian or Triassic red beds in the Delaware basin in Texas; a few fragments of highly sheared granite occur in red-bed conglomerate beneath Jurassic beds in Humble No. 1 Bandera County School Land in Maverick County; granite pebbles and cobbles occur in the Haymond boulder bed in the Marathon area.[22] This granitic terrane cannot be delineated accurately, but it is south of the highly sheared low-grade metamorphic rocks (probably early Paleozoic or late Precambrian) that form an interior zone of the Ouachita structural belt in west Texas and northernmost Mexico and crop out in the Sierra del Carmen; it is east of the Permian deformed belt partly exposed in the Las Delicias-Acatita area; and it is west of the highly sheared slate and metagraywacke encountered in the No. 101 Chapa in Nuevo Leon. It seems reasonable to suggest that this granitic terrane is emplaced in one of the interior zones of the Ouachita structural belt. It can be dated only as pre-Jurassic. If the numerous granite pebbles and cobbles in the Haymond boulder bed of the Marathon Basin (Atokan) were derived from an uplift of this granitic terrane, it is a pre-Middle Pennsylvanian intrusion; if it is related to the granite intrusions of the Las Delicias-Acatita area, it is very late Permian or post-Permian.

In the Cd. Victoria area crystalline rocks of probable Precambrian age, and unmetamorphosed upper and lower Paleozoic rocks of geosynclinal and transitional facies, occur only 80 miles from the Gulf of Mexico. It is difficult to fit these exposures into the tectonic pattern of a Mexican Paleozoic orogenic belt because no regional trends have been established. To the northwest and west there appears to be a broad terrane of variably metamorphosed Paleozoic rocks intruded by granitic igneous rocks, but no information is available on pre-Mesozoic rocks north, east, or south. The crystalline rocks may be part of a massif within the orogenic belt, they may be part of a foreland (eastern?, western?), or they may be part of the crystalline core (by analogy to rocks exposed in the Appalachian piedmont). If they are part of the core, juxtaposition of unmetamorphosed sedimentary rocks of frontal zone type is difficult to explain (p. 102); probably the crystalline rocks are part of an ancient massif or part of a foreland mass.

[21] The following wells bottomed in arkose: No. 1 Treviño, No. 1 Zambrano, No. 1 Chupadero, No. 1 Garza. For descriptions of Cretaceous arkose sections, see Imlay (1944, p. 1079, figs. 8, 11, 12, 13).

[22] The source of the granite pebbles and cobbles in the Haymond boulder bed is not known; if the granite terrane in Coahuila is the same age as the granite in the Las Delicias—Acatita area (very late Permian or post-Permian), the Haymond granite fragments (Atoka age) cannot have been derived from it.

SUMMARY

The presence of deformed and variably metamorphosed late Paleozoic rocks of geosynclinal facies, metamorphic rocks of unknown age, and granitic rocks indicates that northern Mexico was Paleozoic tectonic land. The difference in the age of the Mexican orogenic facies rocks (Permian as against Mississippian in the Ouachita belt to the north) and the difference in the age of the deformation in Mexico (Late Permian as against Late Pennsylvanian-Early Permian in the Ouachita belt to the north) make it unlikely that there is a direct and simple connection between the Ouachita belt in the United States and the exposures of northern Mexico. Recognizing this, P. B. King (1951, p. 157) suggested that the Mexican exposures may be a southwestern extension of an interior zone of the Ouachita system. Another possibility is that the Ouachita system in Mexico developed a younger foredeep along its western foreland and that this downwarp was deformed and intruded in late Permian time. The thick Wolfcamp clastic wedge in the Val Verde basin in Texas, younger than clastic wedges in Ouachita foreland frontal basins to the east and north, indicates that mobility persisted longer in the southwestern part of the belt in Texas, and perhaps in the Mexican segment the advance of the geosyncline over the foreland was carried a step farther.

Igneous Rocks and Vein Rocks in the Ouachita Belt

PETER T. FLAWN

Theoretical Considerations

A developing orogen is a zone of crustal weakness and instability and thus a locus of igneous activity; an igneous cycle accompanies the development of the orogenic system from a geosyncline into a mobile belt. One criterion of a eugeosynclinal sedimentary sequence is its interbedded lavas, generally basaltic or andesitic; the deeply depressed core of the geosyncline is the habitat of syn-orogenic batholiths and migmatites; the consolidated deformed belt, transected by faults and extensively jointed, is commonly invaded by post-orogenic intrusions. Geographic association of older deformed belts and much younger intrusive igneous rocks suggests that post-orogenic adjustments along major structural planes and intersections continued to open channelways for the passage of intrusive igneous material into higher parts of the crust.

At the close of the orogenic cycle the only trace of the early chain of volcanoes that marked the first arc of the incipient orogenic system may be the bedded siliceous deposits in the sedimentary sequence far away along the foreland margin; a deep-seated post-orogenic batholith concealed in the interior zone of a belt may be indicated only by a retinue of dikes cutting the folded and faulted rocks of the frontal zone; the gneisses, schists, and amphibolites of the crystalline core of a belt may be the altered equivalents of sedimentary wedges (containing volcanic or intrusive rocks) that once were like the folded and faulted sedimentary, volcanic, and intrusive rocks that now constitute the frontal zone. If the orogenic forces are not spent, the frontal zone may in time be downwarped and metamorphosed while a younger zone forms along the foreland boundary of the belt.

The Ouachita belt is largely concealed so that the nature of its Paleozoic igneous activity must be reconstructed from very fragmentary evidence.

PALEOZOIC IGNEOUS ACTIVITY IN THE OUACHITA BELT

Areas of Outcrop

The dikes, sills, and other masses of igneous rock which intrude the Paleozoic rocks of the Ouachita Mountains are of Cretaceous age except for two diorite dikes which intrude Ordovician rocks near Glover in McCurtain County, Oklahoma (Honess, 1923, pp. 210–212, 261; Miser, 1943, p. 112; Kidwell, 1949, p. 14). These diorite bodies are extensively fractured and considered to be pre-Late Pennsylvanian (pre-deformation). The plugs, dikes, and sills which intrude Paleozoic rocks in the Marathon Basin belong to the Tertiary igneous suite with one known exception in the southeast part of the Marathon Basin, 30 miles southwest of Sanderson, where basalt or diabase intrudes Ordovician beds and is unconformably overlain by Cretaceous strata (J. L. Wilson, 1954a, p. 2045). There is thus no direct evidence of Paleozoic igneous activity in the two major exposures of the frontal zone of the Ouachita structural belt except for two or three small dikes or sills of intermediate or basic intrusive rock.

In the scattered exposures of pre-Mesozoic rocks in northern Mexico, Paleozoic igneous rocks are common. In the Las Delicias-Acatita area lavas are interbedded with Permian marine sedimentary rocks, and granitic and granodioritic rocks intrude Permian sedimentary rocks (Kellum et al., 1936, pp. 987–988; R. E. King, 1944, pp. 23, 28). At Potrero de La Mula there are granitic rocks which may be Paleozoic in age (Flawn and Díaz G., 1959, p. 224). Ages of intrusives in the Paleozoic rocks of the Sierra del Cuervo and Placer de Guadalupe area are not yet known.

Despite the paucity of direct evidence of Paleozoic igneous activity in the exposed parts of the belt, the sedimentary record provides considerable indirect evidence on igneous activity in the concealed interior parts of the belt.

Early Paleozoic sedimentary rocks contain little indication of contemporaneous igneous activity. In the Marathon region Cambrian(?) and Ordovician beds have a high feldspar content which seems to increase southward; in Dagger Flat the writer observed small pebbles of granite in sandy limestone in the Marathon formation. This arkosic material was probably derived from Precambrian crystalline rocks farther south. Some of the early Paleozoic rocks in the Ouachita Mountains are likewise feldspathic (Goldstein, 1959a, p. 97).

The thick sequences of Ordovician and Devonian chert and siliceous shale in the Marathon Basin and Ouachita Mountains strongly suggest widespread contemporaneous volcanic activity in the more tectonically active parts of the belt to the south, the siliceous sediments being derived from fine pyroclastic material and mixed with fine muds along the foreland side of the belt.

The thick rhythmically deposited sandstones of the Tesnus and Stanley formations are feldspathic and the Tesnus contains beds of arkose (P. B. King, 1937, p. 60); moreover, the sandstones contain metamorphic rock fragments as well as feldspar so that the source may have been a terrane of mixed metasedimentary and igneous rocks. In the Marathon Basin, the succeeding Haymond formation contains massive arkose beds in its upper part and a number of remarkable boulder beds. The Haymond boulder beds contain a suite of rounded igneous and metamorphic pebbles and cobbles as well as fragments of locally derived Paleozoic rocks. The igneous rocks are muscovite granite and granodiorite, in part rudely gneissic, and sheared volcanic rocks, mostly fine-grained porphyries. These may be well-worn fragments from uplifts of the Precambrian foreland to the north but it seems more likely to the writer that, along with the bulk of the other clastic material, the igneous detritus came from an uplift of an interior zone of the Ouachita belt to the south, probably in northern Mexico. The crystalline fragments in the Haymond boulder beds must have been derived from a terrane of mixed plutonic, volcanic, and metasedimentary rocks. The plutonic rocks, from their gneissic character, may have been synorogenic granites or post-orogenic granites subjected to later shearing. The volcanic rocks are strongly sheared and cataclastically altered. In the Ouachita Mountains rocks younger than Stanley are not significantly feldspathic and were apparently derived largely from reworking of pre-existing sedimentary and metasedimentary rocks of the Ouachita belt. The sandstones of the Stanley, however, are markedly feldspathic—the feldspar is, with only minor exceptions, plagioclase and was derived from crystalline rocks, possibly including granitic rocks.

The feldspar content in these Mississippian orogenic facies rocks indicates a crystalline source to the south which may have been (1) an uplifted block of Precambrian crystalline rocks or (2) an uplift of early or middle Paleozoic crystalline rocks like the areas of early Paleozoic and middle Paleozoic intrusive rocks in the Appalachian piedmont (Rodgers, 1952; P. B. King, 1955b, pp. 730–732; Grunenfelder and Silver, 1958; Hurley, Fairbairn, and Pinson, 1958; Long and Kulp, 1958).

Evidence from Subsurface

A number of wells drilled in the frontal zone of the Ouachita belt west of the Llano uplift penetrated Mississippian-Pennsylvanian sandstones that locally contain small fragments of microgranular feldspathic igneous rock, probably volcanic rock, which along with metamorphic rock fragments was probably derived from an uplifted terrane to the south and indicates igneous rocks in the source area.

Igneous rocks have been encountered in a number of wells in the subsurface Ouachita belt (Tables 5 and 6). Determination of their age is a problem, particularly in the case of fine-grained basalt and andesite, where petrographic study of textures and structures is not sufficient to identify positively the rock as intrusive or extrusive. If diagnostic structures and textures of extrusive rocks can be recognized, it can be established that the igneous rock is a flow within the sedimentary sequence and the same age as the enclosing sedimentary rocks, or at least older than the beds above and younger than the beds below. If the igneous rock is intrusive, its age is less certain. If the igneous rocks contain biotite, zircon, thorium or uranium minerals, several methods can be used to determine its absolute age; these methods will be improved and broadened to include other groups of minerals in years to come. For other types of intrusive igneous rocks, it is known only that they are younger than the rocks they have invaded. If the igneous rock is deformed or metamorphosed, it is at least older than the deformation or metamorphism.

In the Ouachita structural belt subsurface igneous rocks which are cataclastically altered or metamorphosed must be older than the late Paleozoic orogeny and either Paleozoic or Precambrian in age. Rocks which are not metamorphosed or cataclastically altered belong to the Mesozoic and Tertiary suites of igneous rocks which have been emplaced in this same area probably as a direct or indirect result of deep structural weaknesses associated with the Ouachita belt. These also have a rather characteristic chemical composition and mineralogy.

Paleozoic or Precambrian Igneous Rocks Encountered in Wells

Nine wells drilled in the Ouachita structural belt or the immediately adjacent foreland have encountered igneous rocks of Precambrian or Paleozoic age (Table 5). Except for Shell Oil Company No. 1 Purcell (Williamson County), which penetrated Precambrian granite gneiss on the foreland edge of the belt, all of these wells are in the western part of the structural belt. In Kinney, Val Verde, and Terrell counties, highly sheared phyllites, schists, marbles, and metaquartzites of the Ouachita belt have been thrust against and over a sequence of sheared metavolcanic rocks of Precambrian age that may be part of the late Precambrian Van Horn mobile belt (Flawn, 1956, pp. 32–35).

The Havoline Oil Company No. 1 Weatherby (Kinney County) and Hiawatha Oil Company No. 1 Sellars (Val Verde County) encountered metavolcanic rocks of probable Precambrian age. They are mostly highly sheared metarhyolite unlike the general suite of Ouachita rocks and resemble more closely the sheared Precambrian rocks of the Van Horn area to the northwest (P. B. King and Flawn, 1953; Flawn, 1956). In the Sellars well, this metavolcanic sequence u n d e r l i e s highly sheared rocks of the Ouachita belt which are probably overthrust. The Precambrian age of these rocks is assumed from their lithologic character and from stratigraphic relations in Richardson Oil Company No. 1 Martin Rose (600 feet northeast of Havoline No. 1 Weatherby) in which an Ordovician fossil occurs in carbonate rocks that lie on the metarhyolite (p. 286). These Precambrian rocks are probably part of a foreland "high" along the northern margin of the Ouachita geosyncline (p. 144 and fig. 2). The sheared basaltic rock in Husky Oil Company No. 1 Rose-Robertson (Val Verde County) to the northwest may be either a part of this Precambrian basement or a pre-shearing intrusion into the rocks of the Ouachita belt. In Terrell County, north of the margin of the structural belt, Magnolia Petroleum Company No. 1 Brown and Bassett penetrated Precambrian basement composed of metavolcanic rock, microgranite, and magnetite-hornblende gneiss and overlain by Cambrian rocks.

In Bexar and Medina counties sheared igneous rocks occur in three wells (Pl. 12). The General Crude Oil Company No. 1 Rogers Ranch encountered highly deformed slate containing masses of brecciated and partly mylonitized granitic rock and underlain by fractured and altered greenstone (andesite). To the west in John I. Moore No. 1 Alfred J. Wurzbach, similar fragments of partly mylonitized granitic rock and volcanic rock occur in a metashale sequence. No cores were taken but the sporadic nature of the igneous material suggests boulders or boulder beds in a slightly metamorphosed shale sequence. In the Rogers Ranch well, cores indicate that the fragments of brecciated granitic rock were tectonically injected into the slate during extreme shearing. Southwest of these two wells, Humble Oil & Refining Company No. 1 E. E. Wilson in Medina County cored brecciated granitic rock overlying sheared and altered greenstone (andesitic and dacitic rocks). Farther southwest in Maverick County, Humble Oil & Refining Company No. 1 Bandera County School Land penetrated steeply dipping sheared and altered greenstones (spilitic? basaltic rocks) partly converted to sericite-chlorite slate (Pl. 12).

The following interpretations of this complex area are suggested:

(1) In the general area of Bexar, Medina, and Maverick counties the Ouachita belt contains volcanic rocks (andesite and basalt) and granitic rocks (granite and granodiorite). Relict textures suggest that the volcanic rocks are extrusive.

(2) The plutonic igneous rocks are brecciated, sheared, and locally mylonitized, and the volcanic rocks are sericitized and chloritized; in Maverick County they are foliated. They are thus older than the final deformation of the Ouachita belt and pre-Middle or Late Pennsylvanian in age.

(3) Whether the granite intrudes the volcanic sequence or is older than the volcanic sequence is not known; the occurrence of granite over the volcanics in Humble Oil & Refining Company No. 1 E. E. Wilson in Medina County may have been caused by faulting.

(4) The granitic terrane was uplifted and shed boulders into an area of shale accumulation to the north. During deformation, these granitic fragments were "squirted" into the shale in the locus of maximum shearing.

(5) The presence of "greenstones" suggests that the concealed southern part of the Ouachita belt is eugeosynclinal in nature.

POST-PALEOZOIC IGNEOUS ACTIVITY IN THE OUACHITA BELT

General remarks.—The area underlain by the Ouachita structural belt has been intruded by both Mesozoic and Tertiary igneous rocks; in places these rocks may be related to Mesozoic or Tertiary fault zones or flexures resulting from renewed movement along pre-existing Ouachita structures.

The igneous rocks of the Balcones fault zone area have been described by Hill (1890), Kemp (1890), Osann (1893), Cross (1900), Lonsdale (1927), Romberg and Barnes (1954), and Greenwood and Lynch (1959); the igneous bodies in the Marathon Basin have been briefly described by P. B. King (1937) and Graves (1954); igneous rocks in the Solitario area were studied by Lonsdale (1940) and Herrin (1959); igneous rocks of the Ouachita Mountains have been described by Kemp (1891), Washington (1900, 1901), Miser (1914), Miser and Ross (1922, 1923), Honess (1923), Lloyd (1923), Ross, Miser, and Stephenson (1928), Croneis and Billings (1929), Miser and Purdue (1929), C. P. Ross (1941), Kidwell (1949), Landes, Parks, and Scheid (1933). Moody (1949) and Kidwell (1949, 1951) studied the igneous rocks of the northern Gulf Coastal Plain. Kidwell lists 159 wells that penetrated igneous rocks (including 26 that encountered pyroclastic rocks) in the northern Gulf Coastal Plain and divided the igneous rocks of the Gulf Coastal Plain into two main petrographic provinces: (1) A diabase-diorite petrographic province which is probably Triassic or early Jurassic in age and certainly pre-Cretaceous; these rocks occur in a relatively narrow east-west belt extending from northeast Texas to northern Mississippi and more or less coincide with a zone of Tertiary faulting and a zone of pronounced flexing or faulting in the pre-Eagle Mills formations. These faults may be manifestations of a deep-seated fault zone which formed the northern boundary of the Gulf Coastal Plain in late Paleozoic or early Mesozoic time. (2) An alkaline petrographic province which is Upper Cretaceous (Woodbine-Taylor) to Tertiary in age; the rocks appear to be older north and east of the Mississippi embayment and younger in south Texas. These, in turn, can be divided into four groups—the Balcones group, the Ouachita group, the central Mississippi group, and the Appalachian foreland group. Only the first two are within the bounds of this study.

The Balcones group of the alkaline province extends more than 200 miles from Austin, Texas, southwestward into Mexico in a belt as much as 40 miles wide. Its rocks are low-silica basalt and gabbro containing olivine, titaniferous augite (and locally aegirine-augite), nepheline, and melilite (Lonsdale, 1927) which form plugs, dikes, sills, and possibly flows. The masses of "serpentine" locally associated with this suite are altered pyroclastic rocks, which in at least some localities are nontronite (Weiss and Clabaugh, 1955). Intrusions of the Balcones type are profuse in Uvalde and Kinney counties, Texas, where the Ouachita belt changes trend sharply, which suggests a relation between Paleozoic structures and younger intrusions. To the east, Balcones-type intrusions are less common but occur as far northeast as the Bell-Williamson County area. Their extent southward into Mexico is unknown.

The Ouachita group of alkaline rocks extends from central Mississippi to central Arkansas in a belt 250 miles long and 100 miles wide which coincides with the Ouachita Mountains and their buried extension to the southeast. Its rocks include nepheline syenite and its fine-grained equivalents, nepheline basalt, and leucite-bearing rocks. Mildly alkaline syenite, diorite, trachyte, and andesite are present in the central part, and these are associated with peridotite, pyroxenite, and various lamprophyres. The

TABLE 5. *Paleozoic or Precambrian igneous rocks encountered in wells in the Ouachita structural belt.*

COUNTY and WELL NAME	APPENDIX REFERENCE	INTERVAL (feet)	ROCK TYPE	GEOLOGY and AGE
BEXAR COUNTY—				
General Crude Oil Co. No. 1 Rogers Ranch	P. 224	5,713 5,894–5,896 TD	Brecciated granodiorite (as augen in slate) Sericitized and chloritized andesite	Extremely deformed slate—locally containing augen of brecciated granodiorite—resting on altered andesite; Paleozoic or Precambrian
KINNEY COUNTY—				
Havoline Oil Co. No. 1 Weatherby	P. 284	4,381±–4,398± TD	Mylonitized (phyllonitized) metarhyolite	Metarhyolite overlain by early Paleozoic carbonate rocks along foreland edge of the Ouachita belt; metarhyolite is probably Precambrian
MAVERICK COUNTY—				
Humble Oil & Refg. Co. No. 1 Bandera County School Land	P. 290	13,332–13,863 TD	Sheared sericitized-chloritized basalt (spilitic?), partly converted to sericite-chlorite slate	Paleozoic or Precambrian
MEDINA COUNTY—				
Humble Oil & Refg. Co. No. 1 E. E. Wilson	P. 295	6,980–7,168 (samples incomplete)	7,065–7,070 feet, cataclastically altered granite 7,163–7,166 feet, fractured and chloritized andesite and dacite	Cataclastically altered granite overlying fractured and altered andesite-dacite suggests complex structural relations or intrusive relations; Paleozoic or Precambrian
John I. Moore No. 1 Alfred J. Wurzbach	P. 295	2,890–3,180	Cataclastically altered granodiorite	Granodiorite (with volcanic and other rocks) appears to occur as cobbles or boulders in a metashale-sandstone sequence; granodiorite is Paleozoic or Precambrian

TERRELL COUNTY—				
Magnolia Petr. Co. and Western Nat. Gas No. 1 Brown and Bassett	P. 307	14,442–14,556 TD	Metavolcanic rocks, microgranite, magnetite-hornblende gneiss	Igneous and metamorphic rocks immediately north of the Ouachita belt on the foreland are overlain by Cambrian beds; Precambrian basement
VAL VERDE COUNTY—				
Hiawatha Oil Co. No. 1 Sellars	P. 322	2,641–3,502 TD	Metavolcanic rocks, mostly metarhyolite	Metavolcanic sequence underlies sheared overthrust (?) low-grade metamorphic rocks of the Ouachita belt; metavolcanics are probably Precambrian
Husky Oil Co. No. 1 Rose-Robertson	P. 324	2,170–2,426	Actinolitic epidote-chlorite-sericite schist	Highly sheared and altered basaltic igneous rocks—greenstone; may be part of Ouachita sequence (Paleozoic), may be part of Precambrian metavolcanic sequence
WILLIAMSON COUNTY—				
Shell Oil Co. No. 1 Purcell	P. 337	9,470–9,485 TD	Granite gneiss	Gneiss is overlain by Cambrian beds along foreland edge of Ouachita belt; Precambrian basement (similar to Town Mountain granite of Llano uplift)

TABLE 6. *Post-Paleozoic igneous rocks encountered in wells in the Ouachita structural belt.*

COUNTY and WELL NAME	APPENDIX REFERENCE	INTERVAL (feet)	ROCK TYPE	GEOLOGY and AGE
BELL COUNTY—				
Nolan Bell Oil Co. No. 2 Wm. Bacon	P. 219	1,805–1,820 (samples incomplete)	Altered olivine gabbro and augite-biotite microsyenite	Probably a post-Paleozoic (Balcones group) intrusion into Paleozoic rocks of the frontal zone of the Ouachita belt
KINNEY COUNTY—				
Magnolia Petr. Co. No. 1 C. B. Wardlaw	P. 285	4,290–4,330 4,960–4,990	Altered olivine(?) microgabbro	A post-metamorphism and probably post-Paleozoic intrusion (Balcones group) into highly sheared rocks of the interior zone of the Ouachita belt
TRAVIS COUNTY—				
G. L. Reasor No. 1 Jesse Ezell	P. 315	?	Olivine basalt	Samples poor; probably a post-metamorphism and post-Paleozoic intrusion (Balcones group) into the frontal zone of the Ouachita belt (olivine basalt also occurs in the overlying Cretaceous section (720–890 feet) but abundance of fragments in the lower part of the well indicates presence of intrusive rock in the Paleozoic sequence)
UVALDE COUNTY—				
Humble Oil & Refg. Co. No. 1 R. L. Anderson	P. 317	4,650–4,685	Olivine basalt (contains nepheline = limburgite)	Probably a post-Paleozoic intrusion (Balcones group) into the frontal zone of the Ouachita belt

largest nepheline syenite bodies are at Magnet Cove and Potash Sulphur Springs, Arkansas. Several hundred dikes and sills related to the plutonic syenite masses are scattered through the eastern part of the Ouachita Mountains. These alkaline rocks of the Ouachita groups are controlled by local structures rather than any major structure (Kidwell, 1949, p. 261); the fracturing that permitted their emplacement was caused by an intersection of the northwest-trending structures of the Ouachita Mountains and northeast-trending structures formed by the downwarp of the Mississippi embayment in Upper Cretaceous time.

The alkaline rocks probably formed as differentiates of an olivine basalt magma (Kidwell, 1949, p. 303) which formed deep in the orogenic belt after the deformation and was tapped by fractures during formation of the Gulf Coast basin.

Post-Paleozoic Igneous Rocks Encountered in Wells Penetrating the Ouachita Belt

Table 6 (p. 114) lists a number of wells in which igneous rocks were encountered within the Paleozoic or metamorphic sequence. These rocks are part of the Balcones group intruded after the deformation and are of basaltic or gabbroic composition. No marked contact metamorphic effects have been noted in the regionally metamorphosed host rocks, but they seem to show more variations in degree of regional metamorphism and more fracturing and veining than are seen in rocks that have not been intruded.[23] These variations may result from local thermal effects caused by intrusive bodies.

Igneous Rocks Intruded in Mesozoic and Tertiary Rocks Overlying or Adjacent to the Ouachita Belt

The numerous bodies of igneous rocks encountered in Mesozoic and Tertiary rocks overlying the Ouachita structural belt were discussed by Kidwell (1949, 1951). Since his study, the No. 1 Garza (76 km. S. 87° W. of Nuevo Laredo in Nuevo Leon, Mexico) penetrated dark amygdaloidal igneous rock within an arkose conglomerate of probable Jurassic age; the igneous rocks appear to be andesite or basalt flows, possibly spilitic. The conglomerates in this well are much like those in Humble Oil & Refining Company No. 1 Bandera County School Land in Maverick County, Texas. In Freestone County, Humble Oil & Refining Company No. 1 Marberry penetrated an olivine basalt between 13,226 and 13,452 feet below Upper Jurassic beds (R. D. Woods, personal communication, 1957). Beneath the basalt is a sequence of hard red quartzitic quartz sandstone containing streaks of red micaceous siltstone and shale (metashale and clay shale); these rocks show very weak to weak metamorphism with a strong hydrothermal element (p. 127) and their age is unknown. Possibly the basalt is a flow on the very weakly metamorphosed quartzitic sandstone terrane. However, E. M. Hurlbut (personal communication, 1958) reported 10 feet of red shale, between the basalt and the quartzitic sandstone, which seems not to be part of the quartzitic sandstone; he suggested that the basalt may lie within the unmetamorphosed Jurassic section and that Jurassic rocks may be faulted against the quartzitic sandstone.

In Shelby County in east Texas, about 150 miles due south of the Ouachita Mountains of western Arkansas, Amerada Petroleum Corporation No. 1 Strickland penetrated igneous rocks at 11,715 feet below a salt and anhydrite sequence of unknown age and bottomed in igneous rock at 12,533 feet. The rocks are altered dacite and altered quartz microdiorite; although some geologists have interpreted this rock as "basement," and therefore probably part of the Ouachita belt, the writer believes it is more likely a younger intrusive body, possibly belonging to the diabase-

[23] No samples of host rocks were available for Nolan Bell Oil Company No. 2 William Bacon (see Table 6), but the position of the well in the frontal zone of the Ouachita belt suggests that the rocks are unmetamorphosed or at the most *incipiently metamorphosed*.

diorite petrographic province of Kidwell (1949). This conclusion is based on the location of the body, the mineralogy and fabric of the rock, and the fine grain size of the upper part of the body.

Two wells in the foreland sequence immediately adjacent to the Ouachita belt are of interest. The Humble Oil & Refining Company No. 1 H. C. Miller in Collin County penetrated basalt in the Ellenburger (p. 242). Because of vesicularity and alteration on the upper surface of this body, some geologists have interpreted it as an extrusive rock which would indicate: (1) Ordovician volcanism in an area of carbonate deposition where all other evidence points to stable shelf conditions, or (2) Ordovician volcanism in the Ouachita belt to the east where other evidence suggests that the environment was such as to favor deposition of siliceous mud. Inasmuch as intrusive bodies highly charged with gas are commonly vesicular and show upper contact phenomena similar to those that characterize flow surfaces (staining, alteration, abundant pyrite, etc.), the writer agrees with V. E. Barnes (personal communication, 1959) that this basalt body is most likely intrusive and related to the Mesozoic period of andesite-basalt intrusive activity.

In Fish Production Corporation No. 1 Postell in Kinney County, foreland sedimentary rocks show sporadic effects of thermal metamorphism. The rocks in the interval 4,695 to 5,371 feet show local development of biotite and amphibole (including sodic amphibole) of metamorphic origin but no directional fabric. Goldstein (personal communication, 1955), after a thorough study of this well, concluded that the metamorphism was caused by a nearby igneous intrusion. Intrusive igneous rock (serpentinized basaltic or andesitic rock) was penetrated just beneath the surface (355 to 465 feet) in this same well.

VEINS IN OUACHITA FACIES ROCKS

General remarks.—Most Ouachita facies rocks both in outcrops and in well cores and cuttings contain abundant vein material, ranging from tiny microveinlets to massive veins as much as 100 feet wide (Miser, 1943, p. 95). Their size, abundance, and mineralogy vary in different parts of the structural belt, and their distribution and mineralogy appear to have tectonic significance.

Miser (1943, 1959) has described quartz veins in the Ouachita Mountains, but there has been no similar study in the Marathon region.

Veins in the Ouachita Mountains

Ouachita Mountains veins are well known for their fine quartz crystals, and a thriving business has grown up in marketing crystals to collectors, manufacturers of various decorative objects, such as fountains, memorials, etc., and manufacturers of electronic equipment.

According to Miser (1943), most of the quartz veins in the Ouachita Mountains are restricted to a belt 30 to 40 miles wide extending west-southwest from Little Rock, Arkansas, to Broken Bow, Oklahoma, which coincides with the main anticlinorial part of the mountains (Broken Bow–Benton uplift). The host rocks range from Cambrian through Pennsylvanian; in the central part of the area the veins apparently occur in all types of rocks, but on the periphery they are best developed in sandstones. The veins are open-space fracture fillings. Quartz (milky, white, vitreous) is the principal mineral, but calcite (and dolomite), dickite, rectorite (a micaceous mineral), chlorite, and adularia occur also. Feldspar (adularia and orthoclase?) is a rare component in Arkansas and in McCurtain County, Oklahoma (Honess, 1923, p. 40), and a few veins contain sulfide minerals, including antimony, lead, zinc, copper, and mercury. The vein rock has been somewhat fractured and crushed. Introduction of the vein material probably took place late in the period of deformation, probably late in the Pennsylvanian, following uplift of the central part of the belt (Miser, 1943, p. 99). There appears to be a correlation between degree of metamorphism and abundance of quartz veins. Miser (1943, p. 99; 1959, p. 39) believed that the sulfide-bearing quartz veins are of the same age as the main suite of quartz veins (Late Pennsylvanian); other geologists (Hess, 1908; Branner, 1932; Scull, 1959) relate these veins to the period of Cretaceous igneous activity.

Ham (1956a) described asphaltite veins in the Ouachita Mountains in southeastern Oklahoma; he pointed out that these veins and fissure fillings are restricted to an east-trending belt about 25 miles wide in the overthrust northern part of the Ouachita Mountains between the Choctaw and Octavia faults, and he concluded that the asphaltic material was derived from underlying normal or Arbuckle facies rocks beneath the allochthonous Ouachita plate.

Veins in the Marathon Basin

Veins are not as conspicuous in the exposed rocks of the Ouachita structural belt in the Marathon Basin as they are in the central part of the Ouachita Mountains. The harder beds in the Marathon Basin are commonly jointed, shattered, slickensided, and penetrated by innumerable small veins of calcite; the Woods Hollow shale contains large veins of fibrous calcite where it is strongly crumpled and overlain by the competent Maravillas chert, and on the southeast side of the basin the massive sandstones of the Tesnus are transversed by veins of quartz and calcite (King, 1937, p. 120). Numerous veins of calcite and quartz penetrate the Tesnus formation in Persimmon Gap south of the Marathon Basin proper.

Veins in the Sierra del Carmen

The metamorphic rocks exposed in the Sierra del Carmen (p. 99) are extensively veined by quartz, carbonate, and chlorite; both pre- and post-deformation veins are present. Locally the schist contains masses or "knots" of milky vein quartz.

Veins in the Subsurface Ouachita Structural Belt

Well cores and cuttings of Ouachita rocks commonly contain quartz and carbonate vein material. The size of the veins, their mineralogy, and their age differ from one part of the belt to another.

Veins are numerous in the frontal zone of the belt but generally are very small. They consist of quartz, calcite, dolomite, or combinations thereof; a distinctive feature is a narrow and irregular concentration of an opaque black bitumen in the center of each veinlet. Veinlets occur in sandstones, cherts, and shales, being most numerous in the first two; the cherts contain numerous fine criss-crossing veinlets. The frequency and habit of the veinlets is a reflection of the type of rock failure. Sandstones and cherts were more prone to fracturing than the shales, and the cherts were susceptible to shattering. The veins appear to be simple fracture or joint fillings emplaced late in or after the deformation.

In the zone of incipient to weak metamorphism, chlorite (vermicular to fibrous) is a common constituent of the quartz-carbonate veins, the veins are larger, and bitumen persists.

South and east of the Luling overthrust front in the zone of low-grade high-shearing metamorphism, quartz-carbonate-chlorite veins are massive and abundant. Some of them contain epidote. Both pre-deformation and post-deformation veins are present. The early veins are broken, contorted, and drawn out in augen; later veins cut across the earlier sheared veins.

No feldspar was observed in the veins which penetrate subsurface rocks of the Ouachita structural belt, even in the zone of low-grade high-shearing metamorphism.

Conclusions

Veins in rocks of the Ouachita structural belt are distributed as follows: (1) in a belt along the foreland side of the frontal zone—mostly small carbonate and quartz veinlets emplaced in open tension fractures and in shattered zones after the main period of deformation and containing bitumen deposited still later in the open spaces remaining; (2) in the interior part of the frontal zone—similar to veins on the foreland side but the presence of chlorite reflects higher temperatures; (3) in the highly sheared interior zone—profuse and commonly massive veins of quartz-carbonate-chlorite-epidote (without bitumen) of two generations; the earlier emplaced before the major shearing, and the later veins in tension fractures younger than the main period of compression.

The relation between vein mineralogy and degree of metamorphism is very close. Chlorite occurs in veins traversing the incipient to weakly metamorphosed rocks, and both chlorite and epidote occur in veins penetrating the highly sheared low-grade metamorphic rocks. Size and profusion of veins are also closely related to metamorphism. They are larger and more numerous in the incipient to weakly metamorphosed rocks than in unmetamorphosed rocks and still more profuse and massive in the highly sheared low-grade metamorphic rocks.

The two ages of veins in the rocks south and east of the Luling overthrust front show that these rocks were extensively veined and probably metamorphosed before they were sheared; the later veins were emplaced after the thrusting and dislocation that produced the shearing.

Metamorphism in the Ouachita Belt

PETER T. FLAWN

General Statement

Regional metamorphism is produced by interaction of thermal, dynamic, and hydrothermal metamorphism, the final product depending on the relative importance of the three processes. In most regionally metamorphosed terranes the mineral assemblage results from recrystallization and reconstitution due to elevated temperatures; the stress environment is reflected in the metamorphic fabric and structures. High pressures and shearing stresses influence the mineral assemblage because some minerals are more stable in high-pressure and/or high-stress environments than others. The hydrothermal component of regional metamorphism is locally important in areas extensively invaded by high-temperature solutions. Adjacent to intrusions the thermal component of metamorphism may produce mineral assemblages unique to the aureole of the invading igneous body (contact metamorphism), whereas in areas of extreme shearing stress the metamorphic products are cataclasites characterized by granulated, sheared (mylonitic) fabrics. Thus, a metamorphic rock is a product of metamorphic environment, and under certain conditions the sum total of its tectonic adventures may be read in its mineralogy and fabric. Retrogressive metamorphism, for example, occurs where a metamorphic rock that has attained equilibrium in a comparatively high temperature environment is brought into an environment characterized by lower temperatures (and commonly high stress), an environment which is common in major overthrusts and nappes. If the rock adjusts completely to its new environment all traces of its former nature will be erased, but where retrograde metamorphic reactions did not proceed to completion, a record remains in the mineralogy and fabric of the rock.

Regional metamorphism is common in orogenic belts, especially in the core and interior zones; it also occurs sporadically in frontal zones. The question of where metamorphism begins and diagenesis ends cannot be resolved by consideration of temperature alone because temperatures in deep wells in foreland basins approach those at which incipient metamorphic reactions are presumed to take place and yet the rocks show no signs of metamorphism. The presence of belts of very weakly metamorphosed rocks in the frontal zones of orogenic belts where high temperatures were not attained seems to indicate that the key is deformation and that low temperature metamorphic reactions are promoted by penetrative intergranular movements during deformation. The grade of metamorphism attained by a rock unit depends mainly on its position within the orogenic belt. In detail, however, the metamorphic grade attained depends also on the relation of the rock to local structures and the susceptibility of the rock to metamorphism (p. 15).

Because of the tectonic significance of metamorphism in the study of the concealed Ouachita belt, Flawn and Goldstein have defined three grades of metamorphism *below* low-grade metamorphism, namely, incipient metamorphism, very weak metamorphism, and weak metamorphism (Table 1); the divisions are made on the basis of degree of reconstitution, recrystallization, and rock structures (p. 15).

Two main metamorphic zones are mapped in the Ouachita belt: (1) a zone of incipient to very weak metamorphism lying irregularly within the frontal zone and (2) a zone of weak to low-grade metamorphism with a strong shearing component which conforms to the interior zone of the belt. Exceptions to these broad generalizations are (a) where metamorphism in the frontal zone is weak or low grade due to local structural conditions, (b) where foreland facies rocks along the frontal margin of the belt are slightly metamorphosed, (c) where rocks of the interior zone approach medium metamorphic grade, and (d) where rocks of the interior zone appeared to have undergone retrograde metamorphism.

Zone of Incipient to Very Weak Metamorphism

Incipiently to very weakly metamorphosed rocks occur in the frontal zone of the Ouachita belt (1) in a broad somewhat irregular arc around the Llano buttress, (2) in the Ouachita Mountains salient where metamorphism increases toward the axis of the Broken Bow–Benton anticlinorium, (3) in a discontinuous band along the northern boundary of the interior zone in Trans-Pecos Texas, (4) associated with local folds and faults in the frontal zone from the Ouachita Mountains to the Solitario, and (5) in a poorly known band along and within the front of the belt extending southeastward from Arkansas County, Arkansas, to Bolivar County, Mississippi. While rocks within the anticlinoria in the Ouachita Mountains salient are metamorphosed, rocks within the anticlinoria of the Marathon Basin are not.

From the eastern Ouachita Mountains to Travis County, Texas, that part of the Ouachita belt's frontal zone next to the foreland is for the most part unmetamorphosed—neither the early Paleozoic or later Paleozoic rocks are significantly metamorphosed. In this part of the frontal zone incipient to very weak metamorphism (and locally higher grade metamorphism) occurs only in the southern and eastern parts of the zone—in anticlinorial structures in the Ouachita Mountains and in a broad band beginning in McLennan County, Texas, and broadening southwestward toward the Llano buttress. The bordering band of incipient to very weak metamorphism generally follows the broadening subcrop of dark clastic rocks, although the metamorphic zone transgresses lithologic boundaries and includes Stanley rocks. In this part of the Ouachita belt, then, it seems to hold generally true that in the *interior* of the frontal zone the pre-Stanley rocks (including the dark clastic unit in central Texas) are metamorphosed to a greater degree than the younger rocks. Possibly the pre-Stanley beds in the interior part of the frontal zones were metamorphosed before Stanley time. Goldstein (1959a) reported evidence from study of sandstones of two geosynclinal cycles, one Ordovician and Silurian and another Mississippian and Pennsylvanian. However, where the earlier beds show the greatest metamorphism, the Stanley, Jackfork, and Atoka beds also are more metamorphosed than elsewhere. An alternative hypothesis, therefore, is that metamorphism in the south and east parts of the frontal zone of the Ouachita belt between Arkansas and the Llano uplift occurred during development of large anticlinorial structures wherein deeper and more altered early Paleozoic rocks were uplifted to their present position in the subcrop. The higher metamorphic grade of the pre-Stanley rocks was thus attained deep in the cores of the anticlinoria. In the Llano area, metamorphism in the frontal zone was probably intensified by crushing against the Llano buttress, but the general coincidence of the belt of metamorphism with the dark clastic unit suggests that this may be another anticlinorial structure.

West of the Llano uplift very weakly metamorphosed Ouachita rocks lie adjacent to unmetamorphosed foreland rocks. The zone of incipient to very weak or weak metamorphism parallels the front and appears to be related to frontal overthrusting and associated deformation. South of the very weakly metamorphosed rocks there is a belt of little altered Mississippian-Pennsylvanian rocks (Tesnus?) which lie next to the Luling overthrust front. Possibly these rocks were not buried as deeply or deformed as much as the metamorphosed rocks to the north.

In Uvalde and Kinney counties where the continuity of the Ouachita belt is lost, Mississippian-Pennsylvanian beds (Tesnus?) with variable incipient to weak metamorphism and cut by intrusive igneous rock were penetrated in Humble Oil & Refining Company No. 1 R. L. Anderson (Uvalde County). Some of the metamorphic effects observed may be due to contact metamorphism related to profuse Cretaceous-Tertiary igneous intrusions in the area.

In Kinney and Val Verde counties where the Ouachita belt was crushed against a concealed foreland buttress and the frontal zone of the belt is either overridden or narrowly developed, incipient to weak metamorphism extends irregularly along the concealed Precambrian element and includes the lower Paleozoic foreland rocks which mantle the old buttress (Pl. 2). Farther west in Terrell County where the frontal zone of the Ouachita belt is well developed in the subcrop, Tesnus and pre-Tesnus rocks are very weakly metamorphosed just north of the terrane of overthrust highly sheared low-grade metamorphci rocks—possibly this is an anticlinorium. Beyond, in Brewster County, rocks of the frontal zone are not metamorphosed.

Zone of Low-Grade, High-Shearing Metamorphism

A zone of low-grade metamorphism (complete reconstitution and recrystallization) with a high shearing component can be mapped in a continuous arcuate band from Navarro County to Medina County, Texas. Continuity of this zone, and that of lithologic units and tectonic units in the Ouachita belt, is lost in Uvalde County, although its persistence is indicated by wells in Frio and Zavala counties (Pl. 2). In Kinney, Val Verde, Terrell, and Brewster counties, a zone of low-grade high-shear metamorphism is again well defined and mappable; it continues southward into Mexico, where control is insufficient for mapping (Flawn and Díaz G., 1959). The western and northern edge of the zone of low-grade high-shear metamorphism is sharply drawn on the map (Pl. 2) and coincides with a structural boundary that is a province boundary as well. This is the boundary of the interior zone of the Ouachita belt herein called the Luling front. This boundary is nearly linear, although it probably occurs more or less irregularly within a disturbed belt some miles wide. The east and south boundary of this zone is beyond the down-dip limit of well control.

Throughout most of the zone, the low-grade chlorite-sericite assemblage persists, but in south-central Texas garnet occurs in some of the rocks and indicates that metamorphism increases southward. Some evidence indicates that the high shearing effected a retrogressive metamorphism in this same area (p. 79).

Low-grade metamorphic rocks also occur in two "metamorphic maxima" in the Broken Bow–Benton anticlinorium in the Ouachita Mountains where metamorphism is clearly related to structure—one "maximum" occurs on the east end of the exposed part of the structure near Little Rock and the other on the west end near Broken Bow (Miser, 1959, pp. 34–37 and fig. 1)—but the metamorphism varies considerably within short distances, and it is dubious whether the persistent zone mapped in subsurface can be extended into these areas. More likely, the Ouachita Mountains metamorphism within the frontal zone of the belt resulted from deformation along the axes of the anticlinoria and was weaker away from those major structures.

Metamorphism East of the Ouachita Mountains

Metasedimentary rocks have been encountered in eastern Arkansas and southeastern Mississippi (p. 91); the few samples available show that metamorphic grade ranges from very weak to low grade, but there is not sufficient control to attempt to delineate metamorphic zones.

Age of the Metamorphism

Attempts to determine by the potassium-argon method absolute ages of the metamorphic rocks in the Sierra del Carmen were inconclusive because divergent ages (240 and 370 million years) were calculated (George Edwards, Shell Development Company, personal communication, 1959). The results do indicate, however, that the *metamorphism* is Paleozoic, whatever the ages of the rocks themselves. Additional inferences as to the age of the metamorphism can be obtained from stratigraphic and structural relations:

(1) In the Ouachita Mountains, Jackfork and Atoka beds are slightly metamorphosed in the central anticlinorium in Arkansas (Miser, 1959, pp. 34–35).

(2) In Bexar County, Texas, post-orogenic Permo-Pennsylvanian beds apparently rest on the metamorphic terrane (p. 125); in northern Louisiana there are post-orogenic beds of Middle to Upper Pennsylvanian age (p. 125).

(3) Atoka sandstones along the front of the belt contain abundant fragments of sheared metasedimentary rocks.

(4) The final deformation of the Ouachita belt in the frontal zone of the Ouachita Mountains was post-Boggy and probably occurred during late Des Moines time.

(5) Metamorphic rocks south of the Luling front contain pre- and post-shearing quartz veins and are locally retrograde rocks.

These data suggest at least two periods of metamorphism, and possibly three, as follows:

(1) Widespread regional metamorphism in the interior of the belt indicated by extensive pre-deformation quartz veins, relict minerals of retrograde rocks, and pre-deformation granites.

(2) Widespread low-grade regional metamorphism with a strong shearing and cataclastic component in the interior part of the belt resulting in shearing of earlier formed quartz veins, retrograde effects in south Texas, and development of mylonites accompanying displacement of the Luling overthrust front. This metamorphism was pre-Atoka because Atoka beds contain abundant fragments of the sheared rocks.

(3) Post-Atoka metamorphism associated with development of anticlinoria in the Ouachita Mountains and intense local deformation in other parts of the frontal zone. This metamorphism was later than the shearing metamorphism in the interior of the belt, (2) above, because Atoka beds contain fragments of sheared rocks. Probably it was post-Atoka and pre-late Des Moines, although there was probably an overlap with the same sort of metamorphism going on in different parts of the belt at different times.

Post-Orogenic Paleozoic Rocks Lying on the Ouachita Belt

PETER T. FLAWN

General remarks.—Four wells have penetrated undeformed and unmetamorphosed late Paleozoic rocks in areas of the Ouachita belt where other data suggest that rocks of the structural belt are strongly deformed or deformed and metamorphosed. These wells are:

(1) Union Producing Company No. 1-E Crossett Lumber Company, Ashley County, Arkansas—12-19S-7W
(2) Union Producing Company No. 1-A Tensas Delta, Morehouse Parish, Louisiana—9-22N-4E
(3) H. A. Pagenkopf No. 1 Max Blum, Bexar County, Texas (p. 226)
(4) Magnolia Petroleum Company No. 1 McKinley, Frio County, Texas (p. 258)

Discussion of Wells Penetrating Undeformed and Unmetamorphosed Late Paleozoic Rocks

According to H. J. Morgan (1952, pp. 2270–2271), the No. 1-E Crossett Lumber Company well in Ashley County, Arkansas, encountered the base of the "Eagle Mills salt" (Louann salt) at 6,485 feet and penetrated 4,651 feet of red shale and sandstone intruded by a number of sills of igneous rock (6,485 to 11,136 feet TD). Kidwell (1949) lists 14 intervals from 6,485 to 10,040 feet that contain igneous bodies and describes the rock as a tinguaite—a nepheline-aegerine phonolite. Morgan considers the "Eagle Mills salt" as Jurassic rather than Permian and the underlying sequence as Paleozoic;[24] he suggests a correlation with the Morehouse formation of northwestern Louisiana.

The No. 1-A Tensas Delta well in Morehouse Parish, Louisiana (p. 350), contains the type section of the Morehouse formation which was proposed to include the 1,190 feet of dark silty shale and thin beds of siltstone and sandy limestone in the interval 9,285 to 10,475 feet (Imlay and Williams, 1942, p. 1672). H. J. Morgan (1952, p. 2271) noted the presence of a few mottled red strata in the sequence. On the basis of pelecypod studies, Imlay and Williams (1942) concluded that the Morehouse formation is late Paleozoic, probably not older than Pennsylvanian; later, in 1954, Hoffmeister and Staplin (1954, pp. 158–159) examined spores from the interval 10,243 to 10,253 feet and concluded that the Morehouse is Middle to Upper Pennsylvanian in age.

In Bexar County, Texas, the Pagenkopf No. 1 Blum well penetrated deep into a sequence of red, green, and gray shale, locally carbonaceous, and containing thin beds of fine-grained sandstone and limestone (4,580 to 7,179 feet) in an area where surrounding wells encountered highly sheared low-grade metamorphic rocks (p. 226 and Pl. 2). The top of this shale sequence seems to correspond with the general elevation of the pre-Mesozoic metamorphic terrane, a surface which dips south at about 200 feet per mile in this area. Thin-section study shows that the rocks are red, brown, green, and gray micaceous silty shale and fine-grained angular poorly sorted micaceous calcareous quartz sandstone containing carbonaceous trash and plant fragments. Some fern and lepidodendron fragments recovered from the 6,734 to 6,737-foot interval have been identified as Pennsylvanian (identifications by R. W. Brown, U. S. Geological Survey, from material submitted by John R. Sandidge, Magnolia Petroleum Company).

Southwest of the No. 1 Blum, the Magnolia No. 1 McKinley in Frio County,

[24] There is some controversy over the position of the base of the Jurassic in this area and the age of the Eagle Mills formation (McKee et al., 1956; this report, p. 86).

Texas, penetrated a sequence of red shale, thin-bedded limestone, sandstone, and conglomerate in the interval 10,380 to 11,910 feet between Lower Cretaceous beds and an underlying terrane of highly sheared low-grade metamorphic rocks. H. J. Morgan (1952, p. 2272) noted that seven limestones between 11,630 and 11,900 feet yielded Lower Permian (Wolfcamp) fusulinids. On the basis of lithologic similarity, he correlated "Wolfcamp" beds in the No. 1 McKinley with the beds in the No. 1 Blum. However, some geologists consider the sequence in the No. 1 McKinley to be Jurassic and explain the presence of Wolfcamp fusulinids as reworked from older beds.

Interpretation of Wells Penetrating Undeformed and Unmetamorphosed Late Paleozoic Rocks

H. J. Morgan (1952) called attention to the occurrence of undeformed and unmetamorphosed late Paleozoic rocks "south and east of the Ouachita folded belt"; he suggested that these beds mark the southern and eastern boundary of the belt, and that the Ouachita belt is a relatively narrow feature (H. J. Morgan, 1952, fig. 1). In addition to the four wells cited herein, Morgan included a discussion of the Standard of Texas No. 1 Mitchell in Grayson County, Texas, to support his thesis. In the writer's opinion, the No. 1 Mitchell is not pertinent to this problem. It is located on the foreland margin of the Ouachita belt and penetrated a normal foreland basin sequence as follows: base of Cretaceous and top of Strawn, 2,370 feet; top of Atoka, 6,735 feet; top of Viola, 9,130 feet; top of Simpson (Bromide), 9,300 feet; top of McLish, 9,770 feet; top of Oil Creek, 10,100 feet; top of Joins, 11,000 feet; top of Ellenburger, 11,240 feet; TD, 11,540 feet in Ellenburger.[25] The "hard black abundantly slickensided and polished shales and quartzitic sands" described by Morgan as unconformably underlying gently dipping Strawn beds are, in the writer's opinion, Atoka and not "Ouachita facies." Apparently in this area Atoka beds were involved in pre-Strawn orogenic movements along the foreland margin of the Ouachita belt. (Immediately to the east, Ouachita facies rocks have overridden Strawn and Atoka beds so there is a record of both pre-Strawn and post-Strawn movements.)

In the writer's opinion, the best explanation of the undeformed and unmetamorphosed Middle or Late Pennsylvanian and Early Permian sedimentary rocks encountered in No. 1-E Crossett Lumber Company, No. 1-A Tensas Delta, No. 1 Blum, and No. 1 McKinley is that they are post-orogenic Pennsylvanian and Permian beds which were deposited in local structural basins within the deformed and metamorphosed Ouachita belt, possibly while final orogenic movements against the foreland to the north were still in progress. Red shale and siltstone, locally with carbonaceous debris, are typical of the youngest group of sediments that characterize an orogenic cycle (Pettijohn, 1957, pp. 636–644). Except where preserved in grabens or other structurally low areas, these post-orogenic deposits were stripped away by post-Paleozoic and pre-Jurassic (in Louisiana and Arkansas) or pre-Cretaceous (in south Texas) erosion. They may be compared to the Triassic Newark group which is preserved in grabens in the piedmont of the Appalachian belt. According to this thesis, the occurrence of these deposits does not define the southern and eastern margins of the Ouachita belt as H. J. Morgan suggested (1952). An interpretation similar to that given herein was presented in 1957 by August Goldstein, Jr., in a paper entitled "Minority Report on the Ouachita Fold-Belt," West Texas Geological Society Guidebook, 1957 Fall Field Trip, pages 26–27.

If this interpretation is correct, these Middle or Late Pennsylvanian and Early Permian deposits indicate, in the areas in which they occur, that the main Ouachita orogeny was over by Middle Pennsyl-

[25] Stratigraphic data from August Goldstein, Jr., personal communication, 1955.

vanian time. This suggests that Van der Gracht's (1931a, p. 1027) idea of Permian orogenic movements is incorrect and that the youngest Ouachita Mountains deformation along the foreland edge of the belt which Hendricks et al. (1947) dated as post-Boggy (post-early Desmoinesian) may well be Desmoinesian or upper Middle Pennsylvanian in age.

The Problem of Humble Oil & Refining Company No. 1 Marberry

Another well, Humble Oil & Refining Company No. 1 Marberry in Freestone County, Teyas (p. 257), also penetrated red beds of post-orogenic facies. However, these rocks are very weakly metamorphosed. The metamorphism is characterized by a strong hydrothermal element rather than the strong shearing component typical of rocks of the interior zone of the Ouachita belt in this general area. This sequence is tentatively interpreted as late Paleozoic post-orogenic beds altered by a nearby igneous intrusion. Some support for this interpretation is found in the fact that the red beds are overlain by basalt, suggesting that there was indeed later igneous activity in the region.

Foreland Basin and Shelf Rocks North and West of the Ouachita Structural Belt

PETER T. FLAWN

General Statement

From Alabama to west Texas, along the foreland boundary of the Ouachita structural belt, are a number of positive and negative foreland structural features; some of these features are positive elements with an early history of stability—part of the older North American craton. They antedate the Ouachita structural belt and acted as foreland buttresses during the late Paleozoic deformation. The deep foreland basins that margin the Ouachita structural belt were certainly actively negative elements during the last stages of the Ouachita belt's mobility because they contain thick accumulations of Late Pennsylvanian and Permian clastic rocks. If the energy that drove the Ouachita belt against the foreland had not been spent, no doubt these foreland basins would have been buckled downward and strongly deformed in their turn. The late Paleozoic basins along the front of the Ouachita belt appear to have been foreland shelves or shallow basins in early Paleozoic time because they contain thick lower Paleozoic carbonate sequences; drilling shows this to be so in the McAlester and Fort Worth basins. Recent deep exploration in the lesser-known Black Warrior, Kerr, and Val Verde basins has proven the presence of sequences of lower Paleozoic carbonate rocks on the order of 2,000 or more feet thick.

The principal positive elements bordering the Ouachita belt are the Ozark, Arbuckle, Criner Hills, Muenster, Llano, Devils River, Fort Stockton, and Diablo uplifts. The principal negative elements are the Black Warrior, McAlester, Fort Worth, Kerr and Val Verde basins.

THE FRONTAL BASINS

Black Warrior Basin

The Black Warrior basin is located in northeast Mississippi and northwest Alabama (Pl. 3) ; it is bordered on the southeast by the Appalachian structural belt and on the southwest by the Ouachita structural belt (p. 85). It has been described by Mellen (1947), Everett (1953), and Braunstein (1958a, 1958b). Unlike the other basins along the front of the Ouachita belt, the Black Warrior basin is cradled in the Ouachita-Appalachian junction so that its sedimentary prism includes detritus from both tectonic lands. A major stratigraphic problem in this basin is the separation of Atoka beds derived from the Ouachita belt and Pottsville beds derived from the Appalachian belt.

The sequence in the basin includes Cambro-Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian beds. According to Mellen (1947, p. 1805), the section exposed in the Birmingham quadrangle (excepting post-Clinton Silurian and Devonian) is representative for most of the basin, and a more or less typical Silurian-Devonian section is exposed in the western valley of the Tennessee River. At the time of Mellen's paper (1947), total thickness penetrated in the Black Warrior basin exceeded 12,000 feet. According to Braunstein (1958a, p. 135), the sequence in the basin is Pennsylvanian (Pottsville), Mississippian (Chester and Iowa), Devonian (Chattanooga), Ordovician (Trenton and Black River), and Cambro-Ordovician (Knox). Cambrian and Ordovician rocks (about 5,500 feet thick) are a thick sequence of dolomite, with subordinate limestone, shale, and sandstone. Silurian and Devonian rocks (less than 1,000 feet thick) are mostly limestone, chert, and shale. Mississippian rocks (about 1,000+ feet thick) are limestone, shale, and sandstone. Everett (1953) and Welch (1959) discussed problems of Mississippian stratigraphy. The Pennsylvanian sequence (thickening from about 8,500 feet in the north to more than 10,000 feet in th south) is sandstone, conglomerate, arkose, and shale with minor limestone beds.

The basin is divisible into two structural provinces. Along the Ouachita front in the southwestern part of the area is an irregular zone of thrust faulting where Cambro-Ordovician and Silurian rocks have been juxtaposed with Pennsylvanian rocks (Atoka?). Farther north in the basin is a northwest-southeast fault zone, along which are eight small gas fields in Upper Mississippian sandstones. Carbon ratios were reported to range from less than 55 percent in the deeper parts of the basin to more than 75 percent in the Appalachian belt (Mellen, 1947, p. 1816).

McAlester Basin
(By August Goldstein, Jr.)

"McAlester basin" was used originally for that part of the Arkansas-Oklahoma Coal basin in Oklahoma, whereas "Arkansas Valley" was used similarly for the Arkansas portion. However, it is more appropriate to use the term "McAlester basin" for the entire basin. Recently the term Arkoma basin has become popular (p. 87).

The McAlester basin is an east-west-trending structural and depositional basin about 50 miles wide and 180 miles long, extending from east-central Oklahoma to east-central Arkansas. It is bounded on the south by the Ouachita Mountains, on the southwest by the Arbuckle Mountains, on the northwest by the Hunton arch, and on the north by the Warner uplift and the Boston Mountains of the Ozark uplift.

The basin contains a thick sequence of Atokan and early Desmoinesian strata resting on foreland pre-Atoka strata and folded into a series of long, relatively tight anticlines, locally faulted along their crests, which are separated by broad synclines.

The only beds exposed in the McAlester basin proper are of Middle Pennsylvanian age (Hendricks et al., 1936). Pre-Pennsylvanian beds include a nearly complete sequence of Paleozoic rocks of Upper Cambrian to Mississippian age, in which there are numerous unconformities and local overlaps. The sedimentary facies is predominantly Arbuckle Mountains or Ozark uplift type and consists of marine shale, limestone, dolomite, and quartzose sandstone, although Maher and Lantz (1953) reported Ouachita facies rocks in the basin north of Little Rock (p. 89). The Pennsylvanian strata are a thick sequence of alternating sandstones and shales which locally contain thin limestone beds and many coal beds. Plant material is abundant in the Pennsylvanian and much of it is probably nonmarine, although some beds in the western and northwestern parts of the basin are of marine origin (Hendricks et al., 1936, pp. 1343–1345).

In Oklahoma, the thickest sedimentary column in the McAlester basin is in the extreme southwestern part, where it is as much as 20,000 feet thick, the greatest bulk being in the Arbuckle group and Atoka formation.

Few wells in the basin have passed through the Arbuckle group of Upper Cambrian and Lower Ordovician age, and none of them were in its deepest part; however, there may be as much as 5,000 feet of Arbuckle rocks in the southwestern portion of the McAlester basin.

The post-Arbuckle Ordovician rocks (Simpson to Sylvan) are relatively thin, not exceeding 1,000 feet. Silurian and Devonian rocks (Hunton group, Woodford) amount to another 400 feet, and the post-Woodford Mississippian (Mayes and Mississippian Caney) may exceed 900 feet. Pre-Atokan Pennsylvanian rocks (Pennsylvanian Caney or "Springer," Cromwell, Union Valley limestone, Union Valley shale, and Wapanucka) possibly amount to 3,200 feet. However, the maximum thicknesses of individual formations do not coincide so that the total thickness in any one spot may be much less than the overall total.

The Atoka is thickest in the extreme southeast part of the McAlester basin in Oklahoma and thins to the northwest. In southeastern Oklahoma it is reported to be 9,000 feet thick (Hendricks et al., 1936, p. 1345), but in the Waldron quadrangle, Scott County, Arkansas, it is probably on the order of 19,000 feet thick.

Post-Atokan Pennsylvanian strata of the McAlester basin (Hartshorne, McAlester, Savanna, Boggy, Thurman, Stuart, Senora) may be as much as 7,000 feet thick, but this total is not present at any one spot. These strata are thickest in central Pittsburg County, Oklahoma, in the west-central part of the McAlester basin.

The McAlester basin varies structurally from place to place. Along its western side the exposed Des Moines beds dip westward at a low angle, whereas the deeper lying pre-Atoka beds dip generally eastward at a variable but fairly rapid rate producing a discordance between surface and subsurface structures. This has resulted from basinward thickening of the Atoka strata.

Most of the folds and faults in the McAlester basin were produced by horizontal compressive forces related to the Ouachita orogeny. These forces were directed northward and northwestward with decreasing intensity away from the Ouachita Mountains. In the Ouachita Mountains, where the compressive forces were greatest, there is much thrust faulting. In the McAlester basin, there are folds and faults roughly parallel to the front of the intensely folded and faulted Ouachita Mountains and trending approximately parallel to the strike of the thrust faults in the Ouachita Mountains. Near the south margin of the McAlester basin the anticlines and synclines are tightly folded and are terminated by thrust faults.

The rocks of the McAlester basin immediately adjacent to the Ouachita Mountains are not metamorphosed, but the sandstones are commonly silicified and contain solid bitumen. Heat and pressure accompanying deformation apparently caused silicification and converted the indigenous oil into solid and gaseous fractions.

In the central part of the McAlester basin the characteristic structure is an alternation of broad open synclines and long, steeply folded anticlines. Some anticlines (Brazil, Hartford) are open and symmetrical with relatively gentle dips along the flanks, but others (McAlester, Adamson, Backbone) are strongly asymmetrical with vertical and overturned dips along the north limb and high-angle thrust faults along the axis.

On the west side of the basin some high-angle faults break through to the surface, but many die out upward so that complexity of structure increases with depth. Many of the faults trend east-west like those of the Arbuckle Mountains structural province (Hendricks, Curvin, and Goldstein, 1950, p. 4), but others are step faults which trend approximately parallel to the strike of the hinge line of the basin.

Along the north margin of the basin the surface strata have a regional west dip, but the underlying pre-Atoka beds dip rapidly southward into the basin. Along the north rim, high-angle step faulting into the basin along the hinge line is intersected by the numerous, subparallel, southwestward-trending faults radiating from the Ozark-Boston Mountain region. Numerous small fault-closed structures formed along the hinge line from this combination of faulting and strong regional south dip in the deeper beds. The faults radiating from the Ozark uplift apparently die out near the north margin of the McAlester basin, but some can be traced in the subsurface considerably farther.

The Fort Smith district of Arkansas farther east in the McAlester basin is divisible into two parts (Hendricks and Parks, 1950). In the southern part the rocks are strongly folded and are broken by a few reverse faults as in the Ouachita Mountains. In the northern part, the strata are deformed only by gentle folds and normal faults, as in the Boston Mountains.

The similarities in lithology and thickness of the pre-Atoka of the McAlester basin to the strata in adjacent areas, such as the Seminole uplift and Boston Mountains, suggest that the McAlester basin developed at the beginning of Atoka time (Hendricks, Curvin, and Goldstein, 1950). The Atoka formation generally thickens southward, and in Atoka time the McAlester basin was only the northern part of a larger basin that also included the Ouachita Mountains.

Deformation within the McAlester basin began during Atoka time and continued at least into post-Thurman (middle Des Moines) time, probably culminating even later. Continued deformation is indicated by unconformities at the bases of major sandstone formations, by intraformational conglomerates, and by pronounced thinning of strata over major structures. The absence of the Hartshorne sandstone in the Ouachita Mountains to the south of the McAlester basin suggests that at the end of Atoka time the Ouachita Mountains region was uplifted sufficiently to be above sea level, so that the original limits of the McAlester basin were only slightly different than those defined by present occurrences of the Hartshorne sandstone on the surface and in the subsurface (Hendricks, Curvin, and Goldstein, 1950, p. 6). A final stage in the structural history of the basin was regional westward tilting that probably resulted from uplift in the central part of the basin; it may have occurred as late as post-Cretaceous time.

The entire McAlester basin has possibilities for gas production on favorable structures. Gas has been produced from sandstones of Morrowan, Atokan, and Desmoinesian age, from the Viola limestone (Ordovician), and from the Hunton limestone (Silurian-Devonian). Most of it has been dry gas, but wet gas has been produced from several areas on the eastern side of the basin, and oil was produced from Cromwell sandstones and sandstones of the Simpson group in Coal County, Oklahoma, at the extreme western margin of the basin. Adequate porosity and permeability, low to moderate carbon ratios, and presence of a favorable sedimentary facies suggest that the western and northern rims of the McAlester basin are potentially favorable for the occurrence of oil in suitable structures.

Grayson County Area

Between the northwest-trending Muenster element and the northwest-trending Amarillo-Wichita-Criner element is a deep narrow basin variously called the Marietta basin, Marietta-Sherman basin, or Marietta syncline. The Ouachita belt is thrust over the southeastern end of this basin and oil and gas have been discovered immediately west of it. Hence, many well data are available on foreland facies rocks adjacent to the Ouachita belt.

No Cambrian beds have been penetrated in the Marietta basin, but as they are known on the Muenster uplift in Cooke and Denton counties they probably occur in the deeper parts of the basin. Ordovician beds, including Ellenburger and Simpson groups and Viola limestone, may be as much as 8,000 feet thick, according to Bradfield (1957, pp. 44–45); the lower part of the sequence is mostly limestone and dolomite and the upper part, limestone and shale with minor sandstone. In early Paleozoic time the Marietta basin was probably a subsiding shelf or shallow basin. Devonian and Lower Mississippian beds are represented by the Woodford formation, mostly dark shale as much as 1,000 feet thick, which lies disconformably on older rocks.

The Marietta basin contains a thick sequence of Pennsylvanian clastic rocks of Morrowan(?) to Virgilian age and consisting of shale and sandstone with thin limestone beds, similar to those in basins to the northeast and south. Pennsylvanian beds truncate older rocks. The thickest units are Atoka (Dornick Hills) and Strawn (Deese). Folding and faulting during Pennsylvanian sedimentation produced local truncations, so that the thickness of the Pennsylvanian beds varies greatly. According to Bradfield (1957, pp. 26–28), Atokan-Morrowan(?) and Strawn strata attain a maximum thickness of 12,500 feet. Younger Pennsylvanian beds aggregate 2,500 to 3,000 feet thick.

Foreland facies beds near the Ouachita front are sharply folded and overturned toward the west and are cut by both high-angle reverse faults and younger normal faults (Bradfield, 1957, fig. 5). The "Red" Strawn (upper Strawn) thickens and coarsens eastward with an accompanying increase in the amount of varicolored chert fragments of Ouachita derivation. According to Bradfield (1957, p. 37), Ouachita folding and uplift must have preceded or been contemporary with deposition of the "Red" Strawn, and final thrusting was later.

The Ouachita front in Grayson County is marked by an overthrust (Pl. 2 and fig. 13) which brings lower Paleozoic Ouachita facies rocks over Strawn (Deese) beds. Structural relations and lithology of the Strawn beds indicate that overthrusting occurred within or immediately following Strawn time with tilting and normal faulting later in the Pennsylvanian (Missourian or Virgilian). Where Ouachita rocks have been thrust against the Marietta basin they have overridden northwest-trending structures such as the Sherman anticline. A well on the southeast end of the Sherman anticline, Tennessee Gas Transmission Company No. 1 Washburn, penetrated Atoka beds lying on deeply eroded Simpson rocks (Oil Creek), indicating that the northwest-trending structures are pre-Atoka.

Oil and gas in the Grayson County area are produced from Strawn (Deese), Atoka (Dornick Hills), and Simpson (Oil Creek) formations.

Fort Worth Basin

The Fort Worth basin is in north-central Texas (Pl. 2). It is bounded on the east by the Ouachita structural belt, on the south by the Llano uplift, on the north by the Red River uplift (Muenster and Electra elements), and on the west by the Texas arch (in some papers the western boundary is given as the Bend arch, a Middle or Late Pennsylvanian axis of tilting). Excellent summaries of the geologic features of this basin are given by O. D. Weaver (1956) and Turner (1958).

The sedimentary sequence in the Fort Worth basin includes Cambro-Ordovician, Devonian, Mississippian, and Pennsylvanian rocks, all of which, except the Upper Ordovician, are exposed along the northeast side of the Llano uplift. Maximum sedimentary thickness is about 12,000 feet (Turner, 1958, p. 57); the deepest part of the basin is to the northeast, in western Dallas and southeast Denton counties. Precambrian basement rocks have been encountered at 7,660 feet in Parker County and at shallower depths along the south and west margins.

The Cambro-Ordovician (possibly attaining a thickness in excess of 3,500 feet in the eastern part of the basin) is a thick sequence of carbonate rock (Ellenburger) with subordinate sandstone and shale. Upper Ordovician rocks (Simpson and Viola) occur only in the northeast part of the basin. Devonian strata form thin (less than 20 feet thick) patches on the Cambro-Ordovician surface in the Llano uplift area but have not yet been found in the subsurface. Mississippian rocks range from 200 to 500 feet thick and are mostly shale and limestone. The Pennsylvanian is mostly clastics (sandstone, shale, and conglomerate) with thin limestone beds to the west and north. According to Turner (1958, p. 65), Morrow and Atoka beds thicken from less than 250 feet in the north to more than 6,000 feet along the Ouachita front, and their maximum original thickness may have been as much as 10,000 feet.

The Strawn ranges from 1,500 feet thick in the west to more than 4,500 feet thick in Denton and Wise counties. Canyon and Cisco beds are preserved in the north and west parts of the basin; the Canyon is 750 feet to 2,000+ feet thick and the Cisco is 600 feet to 1,000+ feet thick.

The eastern margin of the Fort Worth basin along the Ouachita orogenic front is poorly known and structurally very complex. In some areas Ouachita facies rocks of lower Paleozoic age have been thrust over Atoka beds. At the south end of the basin in Bell County the minimum displacement on this overthrust front is about 6 to 8 miles (Pl. 2). Paleozoic rocks of the Fort Worth basin must have been strongly folded and faulted near the Ouachita front.

On the north near the Muenster uplift the basin is bordered by northwest- and west-trending faults which have raised basement rocks about 5,000 feet on the northeast; this faulting was pre-Canyon and probably post-Mississippian. Lower Atoka beds near the faults contain arkose derived from the uplifted basement rocks in the Muenster and Electra elements. Positive movements of the Llano uplift are also pre-Canyon; according to Cheney and Goss (1952, pp. 2237, 2246, 2262), the area was one of alternating uplift and subsidence subsequent to deposition of Ellenburger rocks.

Structural contours on top of the Ellenburger show a regional slope of about 50 feet per mile from the outcrop in the Llano uplift area to a −10,000-foot contour against the fault zone on the southwest side of the Muenster uplift. In early Paleozoic time the area was apparently a shelf or shallow carbonate basin. Whatever Silurian and Devonian sediments were deposited in the area were removed by pre-Mississippian erosion. The thin dark phosphatic shales and spiculitic-crinoidal limestones of Mississippian and earliest Pennsylvanian age indicate restricted calcium carbonate and mud deposition.

During Late Mississippian time orogenic activity in the Ouachita belt was advancing westward toward the Fort Worth basin, and a thick clastic wedge of Stanley beds was being deposited to the east. As this Stanley trough was deformed, uplifted, and pushed westward, a rapidly subsiding Atoka trough formed on the site of the Fort Worth basin and received Ouachita-belt detritus from the east and Muenster-Electra-uplift detritus from the north. Deformation and uplift of the Atoka deposits along the eastern margin of the basin with thrusting of Ouachita facies rocks over them resulted in a shift of the major axis of Strawn deposition to a position west of that of the Atoka. Ouachita orogenic activity continued into Strawn time, as Bigfork and Womble rocks (lower Paleozoic Ouachita facies) are thrust over Strawn beds in Grayson County, northeast of the Fort Worth basin. Farther south, however, there is no recognizable Strawn along the Ouachita front, and Ouachita facies rocks are thrust over the Atoka. Turner (1958, p. 76) mapped the subcrop contact between Atoka and Strawn northeast from its outcrop in the Llano uplift in Mills County, through Hamilton, Hood, Tarrant, and northwest Dallas counties. The position of the present subcrop contact is the result of post-Canyon erosion; Cheney and Goss (1952, p. 2251) stated:

> Epeirogeny of the Ouachita Mountain region and westward tilting of the central Texas region apparently did not begin until after Canyon time. This conclusion is based on (1) eastward thickening of Atoka to Canyon beds, (2) eastward deepening of channels in the upper Canyon, and (3) westward thickening of Cisco and Permian beds.

Three possible interpretations account for the absence of Strawn along the Ouachita front in the Fort Worth basin: (1) Strawn beds were never deposited because of local post-Atoka—pre-Strawn uplift; the major period of frontal thrusting, as dated in the Grayson County area, was late Strawn or post-Strawn. (2) Frontal thrusting along the Ouachita belt in the Fort Worth basin was post-Atoka and pre-Strawn (earlier than in Grayson County), and any Strawn rocks deposited after the overthrusting have been removed by erosion. (3) Strawn beds were involved in the frontal structures of the Ouachita belt and are preserved therein but have not been recognized because they are of a different facies than the western Strawn rocks; according to this hypothesis, the thick wedge of tectonic sediments deposited along the front of the Ouachita belt in the Fort Worth basin includes both Atoka and Strawn but the Strawn limestones (containing the Strawn fauna) were developed only farther west, at some distance from the front. The third hypothesis derives some support from Turner's observation (1958, p. 71) that there seems to be no significant unconformity between Strawn and Atoka beds, and that their lithologic differences are minor. Strawn shales are less micaceous than Atoka shales, and Strawn conglomerates to the north are more arkosic than those lower in the sequence. However, in Grayson County, on the other side of the Muenster uplift from the Fort Worth basin, lower Paleozoic Ouachita facies rocks are thrust over normal Strawn beds. Unless the frontal thrust in this area has a much greater displacement than farther south so that the facies change has been overridden, there was no marked facies change in Strawn beds deposited close to the Ouachita front. The writer favors hypothesis (1) above and believes that the abundant chert and novaculite fragments in the upper Strawn and lower Canyon conglomerates are stratigraphic evidence that the structural belt was an active source area at this time, probably as a result of the orogenic paroxysm that culminated in the frontal overthrusts.

The complex structures which are concealed along the eastern edge of the Fort Worth basin are probably similar to those along the southwestern edge of the Val Verde basin and the northern edge of the Marathon region; in both areas deep drilling has proved the presence of a normal basin section below overthrust Ouachita facies rocks (p. 57). In the eastern part of the Fort Worth basin, Bigfork chert and Womble shale have been thrust over Atoka beds (Strawn and Atoka in Grayson County) which in turn are underlain by a normal lower Paleozoic basin sequence; along the northern edge of the Marathon Basin, Caballos novaculite has been thrust over Pennsylvanian and Wolfcamp(?) beds which overlie a normal lower Paleozoic basin sequence.

In the southern end of the Fort Worth basin there are northeast-trending normal faults which can be traced into the subsurface from the outcrop in the Llano uplift (Cheney, 1929b, Pl. VIII; Turner, 1958, p. 74).

Oil and gas production in the Fort Worth basin is mainly from Mississippian and Pennsylvanian rocks in the northern and western parts of the basin and to a lesser extent from Ordovician rocks in this same area. There is also some small gas production from Lower Pennsylvanian rocks (Marble Falls limestone) on the south margin of the basin.

Paleozoic Trough East and South of the Llano Uplift

East and south of the Llano uplift in parts of Bell, Travis, Blanco, Hays, and Kendall counties, wells and seismic studies indicate a narrow, arcuate, very thick body of Paleozoic rocks between rocks of the Llano uplift and the Ouachita facies rocks in the Ouachita structural belt. The intervening rocks appear to be foreland facies rocks deformed when the Ouachita prism was crushed against the Llano buttress. The trough in which they lie apparently connects the Fort Worth and Kerr basins around the southeast bulge of the Llano uplift. Seismic interpretations indicate that the sedimentary rocks are more than 12,000 feet thick[26] in western Hays and Travis counties so that the Precambrian basement rocks exposed in the Llano uplift drop off sharply to the southeast.

Most wells along the southeastern edge

[26] Personal communication; source prefers to remain anonymous.

of the Llano uplift penetrate a typical shelf sequence of Atoka, Marble Falls, Barnett, and Ellenburger, but in some wells Cretaceous rocks rest directly on Ellenburger. Along the southeastern margin of the shelf, however, the Atoka sandstones are of orogenic facies and contain abundant chert and phyllite fragments and a higher percentage of feldspar (10 to 15 percent more) than normally. The shales are brecciated and deformed, and there is an indication of incipient metamorphism in both shales and sandstones. These rocks reflect active tectonism in their source areas and apparently took part in subsequent orogenic movements (Shell Oil Company No. 1 Harwell, Hays County; Summerow No. 1 Reimers, Franklin No. 1 Reimers, and Cypress Creek Drilling Association No. 1 Romberg, Travis County). One of the most significant wells in this trough is Shell Oil Company No. 1 Purcell in Williamson County, which penetrated over 6,000 feet of Atoka beneath which are Marble Falls—Barnett, Ellenburger, Cambrian, and Precambrian granite gneiss of Town Mountain type. This well demonstrates the abrupt southeastward thickening of Pennsylvanian beds into the trough.

Kerr and Val Verde Basins

West of the Llano uplift, the Ouachita structural belt is bordered on the north by a long narrow Pennsylvanian-Permian basin which trends west-northwest. Its eastern part, in parts of Kerr, Bandera, Real, Edwards, Uvalde, and Medina counties, is the Kerr basin; the western part, including parts of Edwards, Kinney, Val Verde, Terrell, Crockett, and Pecos counties, is the Val Verde basin. The boundary between the two basins is an arch extending approximately north-south through Edwards County where the Pennsylvanian sequence thins. Although related structurally, the two basins differ in stratigraphy. The Kerr and Val Verde basins are bordered on the north by the Llano uplift, Eastern shelf, and the south end of the Central Basin Platform. The western end of the Val Verde basin connects northwestward with the Delaware basin. A Late Permian successor of the Val Verde basin is known as the Sheffield channel.

Despite extensive drilling for oil north of the Kerr and Val Verde basins, surprisingly little is known about them. The Val Verde basin is the subject of current wildcat efforts, and more is known about this area than about the eastern part of the basin.

The sequence in the Kerr basin is similar to that in the Fort Worth basin, and the same stratigraphic terminology can be used. Its sequence includes Ordovician (Simpson and Ellenburger), Mississippian (Barnett-Chappel), Pennsylvanian (Marble Falls and Atoka), and Lower Permian (Wolfcamp). Mississippian rocks are mostly restricted to the east and Simpson beds to the west. Pre-Cretaceous and post-Ellenburger rocks in the Kerr basin are 8,000 to 9,000 feet thick and are mostly dark clastics of Atokan age. A thin Mississippian section occurs between the Atoka and Ellenburger to the east. To the west the upper part of the dark clastic rocks is considered by some geologists to be of Wolfcamp age. Some wells in the Kerr basin have penetrated Ellenburger carbonate rocks but were abandoned after drilling a thousand feet or less into Ordovician strata. Presumably Cambrian rocks underlie the Kerr basin but no wells have reached Cambrian or basement in the basin proper.[27] One of the thickest sections in the Kerr basin was penetrated in Phillips Petroleum Company No. 1-A Carson in Edwards County: top of Wolfcamp, 1,090 feet; top of Pennsylvanian, 3,140 feet; top of Simpson, 9,500 feet; top of Ellenburger, 9,657 feet; total depth, 9,970 feet in Ellenburger.

The Val Verde basin to the west contains

[27] The Magnolia Petroleum Company No. 1 Ed Below, Kendall County, on the eastern edge of the Kerr basin penetrated a pre-Pennsylvanian Llano uplift section including Marble Falls, Barnett, Chappel, Doublehorn, Ives, Ellenburger, Wilberns, Morgan Creek, Welge, Lion Mountain, and Cap Mountain.

a thicker sequence which is more like the west Texas Permian basin section than the Llano uplift section. The only basement test in the basin topped Precambrian rocks at 15,442 feet (Magnolia Petroleum Company No. 1 Brown and Bassett, Terrell County); a deeper test in Val Verde County (Phillips Petroleum Company No. 1 Wilson) was abandoned in Cambrian beds (Wilberns) at 16,456 feet. Another Phillips well (No. 1 Elsinore Cattle Company) drilled on the Sierra Madera in Pecos County spudded in Leonard and was abandoned in Pennsylvanian (Cisco) at 12,096 feet. The Sierra Madera is an anomalous structure so that the thickness penetrated in this well cannot be used in a general stratigraphic picture. The deepest well in the Val Verde basin and currently the deepest well in the world is Phillips Petroleum Company No. 1-EE University, which bottomed in Ellenburger at 25,340 feet. Addison Young (1960) estimated that the bottom of the well is about 1,000 feet above the basement. About 7 miles to the north, Shell Oil Company (Humphries) No. 1 University encountered basement rocks at 4,809 feet on the southern edge of the Pecos arch (Fort Stockton high), demonstrating a structural displacement of more than 21,000 feet. The Val Verde basin contains a complete Paleozoic sequence including Cambrian (100 ± feet), Ordovician (Ellenburger, 1,500 ± feet; Simpson, 500 to 1,200 feet), Silurian (300 ± feet), Devonian (500 ± feet), Mississippian (50 ± feet), and Pennsylvanian-Permian (13,000 ± feet). More than 13,000 feet of the total 16,000 to 17,000 feet of known section is Pennsylvanian-Permian, and Frenzel (1957, p. 2) estimated that as much as 10,000 feet of Lower Permian (Wolfcamp) rocks may be present in Terrell and Pecos counties. Addison Young (1960) calculated maximum Wolfcamp thickness as close as 14,000 feet. The sequence from Cambrian through Strawn in the Val Verde basin appears to be normal west Texas basin sequence of carbonates and clastics without excessive thickness of Atoka and Strawn rocks. The Ellenburger is of typical carbonate facies throughout the Val Verde basin, whereas younger Paleozoic beds change in facies from predominantly clastic facies in the basin proper to a carbonate facies farther north.

The Pennsylvanian-Permian boundary north of the Marathon area and in the Val Verde basin has been much debated; new fusulinid evidence suggests that much of the dark clastic rocks that had been considered post-Strawn Pennsylvanian are of Wolfcamp age. However, the type section of the Wolfcamp in the Wolfcamp Hills northeast of Marathon consists of only 500 to 600 feet of shales, thin limestones, and conglomerates resting on older rocks with strong unconformity and overlain by Leonard beds. This strong unconformity is also present in the western Glass Mountains (Decie ranch area) where it is marked by a coarse conglomerate at the base of the fossiliferous Wolfcamp beds.

P. B. King (personal communication, 1957) remarked that the new fusulinid data indicate several possibilities: (a) Beds both above and below the unconformity in the Decie ranch area are equivalent to parts of the Wolfcamp at its type locality, that is, the unconformity corresponds to some level within the Wolfcamp at the type section. (b) The beds below the unconformity in the Decie ranch area contain fusulinids of Wolfcamp type but are pre-Wolfcamp and post-Virgil in age, representing deposits laid down rapidly along the edge of the mobile belt when little was deposited elsewhere. (c) Wolfcamp-type fusulinids (*Pseudoschwagerina* and *Schwagerina*) range down into the Virgil series, or to a lower level than heretofore supposed. The imputations of Wolfcamp age for the beds below the conglomerate fail to consider the collections of fossils made earlier from the Gaptank formation west of Marathon and the vicinity of the Decie ranch which include fusulinids, ammonoids, brachiopods, etc., that range from Des Moines to Virgil—

these include collections made between the Decie ranch and milepost 580 on the railroad that contain *Triticites secalius*, a Virgil fusulinid (P. B. King, 1937, pp. 80–82). The important question raised by King (personal communication, 1957) is whether the Wolfcamp series should be defined on the basis of beds correlative with those of the type section, or on the basis of occurrence of *Pseudoschwagerina*, *Schwagerina*, and other alleged Wolfcamp index fossils, regardless of where they occur in the sequence.

The question of the age of the thick clastic section in the Val Verde basin is far from academic because these sediments record orogenic movements in the structural belt and therefore serve to date the orogeny in this part of the belt. The difference between the Val Verde basin and frontal basins to the east and north is that its major downwarp was post-Strawn rather than Atoka. Tectonic activity (uplift of source area and downwarp of frontal basin) in this area, therefore, continued later than in the area to the east—throughout the Pennsylvanian if the clastic wedge is post-Virgil and into Lower Permian time if the clastic wedge is Wolfcamp. Farther southwest in Mexico weakly metamorphosed but strongly deformed Paleozoic rocks are of Wolfcamp age (p. 104). If the thick post-Strawn clastic sequence if of Wolfcamp age, the Canyon and Cisco beds must be missing, so that the Wolfcamp rests directly on Strawn.

The southern margin of the Kerr and Val Verde basins is structurally very complex. As in the other frontal basins, the Ouachita mobile belt was thrust against the basin from the south, and in some areas Ouachita facies rocks have overridden foreland rocks along the south side of both the Kerr and Val Verde basins. The trace of one such fault, the Dugout Creek overthrust, crops out in the Marathon Basin (Pl. 2). As an additional complicating factor, there is a concealed Precambrian buttress in Kinney and Val Verde counties along the south edge of the Val Verde basin (p. 144). Although no commercial oil fields have been discovered in the Kerr and Val Verde basins, there are commercial gas fields in Terrell, Val Verde, and Kinney counties (Goode, Pandale, Morrison, Vinegarone fields). A major gas discovery was made in 1957 in Magnolia Petroleum Company No. 1 Brown and Bassett in Terrell County. Gas is being produced in the basin from Ellenburger, Devonian, Pennsylvanian, and Permian rocks. Drilling in the Val Verde basin has revealed steeply tilted beds and thrust or reverse faults. Thus, as in the McAlester basin, paroxysms of the Ouachita orogeny folded and faulted the sedimentary rocks of the basin.

The southern boundary of the Kerr basin in Uvalde and Kinney counties is not known. The Ouachita belt itself cannot be traced, and there are abundant intrusions of Cretaceous-Tertiary igneous rocks.

Basins East and South of the Known Course of the Ouachita Belt

In northern Florida, southern Georgia, and southeastern Alabama, some wells have encountered lower Paleozoic beds of Cambrian to Devonian age whose composite thickness is more than 6,000 feet (Applin, 1951; Bridge and Berdan, 1952; Braunstein, 1958a, p. 137). These Paleozoic rocks, mostly shales and sandstones, are termed the Suwanee River basin by Braunstein (1958a, p. 137) and the Suwanee basin in this report (p. 90). If this basin, like the Black Warrior, McAlester, Fort Worth, Kerr, and Val Verde basins, is a frontal basin whose development was initiated by the Ouachita orogeny, its location suggests that the Ouachita belt borders it on the southwest (Pl. 1). However, its lack of late Paleozoic rocks indicates that it differs from the other frontal basins so that comparison with them must be made with reservations. P. B. King (1950, pp. 657–658) suggested, with reservations, that this basin marks the southeast flank of the Appalachian system.

Some Paleozoic rocks are exposed in the poorly known area of northern Mexico south of the last exposure of the Ouachita structural belt in the Solitario uplift of west Texas (Pl. 1 and fig. 5). Part of the rocks are flysch-type orogenic sediments which resemble the Tesnus and may be Ouachita facies, but other exposures seem to be foreland rocks (p. 99). Perhaps a Paleozoic frontal basin exists in northeastern Chihuahua northwest of Ojinaga and north of Placer de Guadalupe.

Summary

The stratigraphic record and the structure of the frontal basins of the Ouachita structural belt provide much information useful in reconstructing the history and development of the Ouachita system. The lower Paleozoic sequence shows that the early Paleozoic foreland of the Ouachita geosyncline was a more or less stable shelf on which thick carbonates and fine clastics were deposited. The abundant siliceous material in the chert and siliceous shale of the Devonian and other systems is a foreland reflection of distant volcanic activity in the mobile area to the south and east. Mississippian shales indicate continued fine clastic deposition in the foreland while the geosyncline was advancing closer toward the craton. Pennsylvanian (Atoka and early Strawn) clastic wedges in the Black Warrior, McAlester, Fort Worth, and Kerr basins record strong foreland downwarps in response to the thrust of the mobile belt against the foreland; later Strawn-Canyon rocks in this area are post-orogenic products derived from the uplifted geosynclinal rocks. The latest foreland basin downwarp in the Val Verde basin to the west was of post-Strawn and possibly mainly Wolfcamp age. Orogenic activity thus probably continued longer in the western part of the Ouachita belt.

Ozark Uplift

The Ozark uplift is a slightly elliptical domical area in southern Missouri, northern Arkansas, and northeastern Oklahoma whose long axis extends nearly 400 miles northeast-southwest. Its highest part exposes Precambrian, Cambrian, and Ordovician rocks, and Mississippian and Pennsylvanian beds dip away around the periphery of the uplift (Dake and Bridge, 1932; Huffman, 1958).

The exposed Precambrian of the Ozark uplift is granite and rhyolite porphyry. Upper Cambrian sandstone, locally conglomeratic, is overlain (in ascending order) by thick dolomite, limestone, shale, and dolomite, which were deposited on a hilly Precambrian surface with as much as 1,300 feet of relief in Oklahoma and nearly 2,000 feet of relief in Missouri (Dake and Bridge, 1932, p. 630). The Cambrian ranges from a thin veneer to as much as 1,000 feet thick; most of it lies flat, but in places there are steep initial dips of 30 degrees in the lower part. Lower Ordovician rocks overlap the Cambrian sediments and in places rest directly on the Precambrian; the Ordovician is dolomite overlain by limestone, dolomite, sandstone, and shale; it is as much as 1,500 feet thick in the central area and attains 3,500 feet in southwest Arkansas. No Silurian and Devonian rocks occur at the surface except in scattered outcrops, but both systems are represented in subsurface on the flanks of the uplift. Silurian and Devonian rocks are thin limestone, chert, and shale with minor sandstone; the Silurian is as much as 250 feet thick and the Devonian is as much as 600 to 700 feet thick on the flanks of the uplift. The older Paleozoic rocks are overstepped by Mississippian and Pennsylvanian beds, and Pennsylvanian beds may have covered the dome completely at one time (L. H. White, 1926, Pl. 1). The Mississippian rocks are black shale, fossiliferous limestone, and chert which are overlain by limestone and sandstone that grade upward into a sandstone-shale sequence of Atoka age and pass into a shale-coal section. Mississippian rocks are about 500 feet thick in the central area and 1,500 feet in central-eastern Missouri; Pennsylvanian rocks are as much as 2,500 feet thick. The Pennsylvanian sequence thickens very rapidly into the adjoining basins.

The Ozark uplift was positive throughout much of Paleozoic time. The earlier Paleozoic rocks thin toward the crest of the uplift and the younger Paleozoic beds are unconformable on the older rocks. Mississippian and Pennsylvanian beds rest directly on Lower Ordovician rocks in the area of maximum uplift. Successive unconformities record both uplift and tilting. Epeirogeny occurred in Upper Cambrian time (pre-Potosi), at the end of Silurian time, in late Devonian or pre-Mississippian time, late in the Mississippian, and in Early and Middle Pennsylvanian time (Huffman, 1958, pp. 105–109). Although the present uplift is more or less domical, the pre-Mississippian feature was elongate east-west or northwest-southeast, perhaps connecting with the Ellis, Chautauqua, and Hunton arches farther west. Northwest-trending faults and folds cross the Ozark uplift and there are northeast-trending faults in the southwest part of the dome. According to Huffman (1958, p. 109), major deformation in the area is the result of tension in Middle Pennsylvanian time produced by basin loading and cessation of the compressional forces of the Ouachita orogeny. River terraces along the Grand and Arkansas Rivers may indicate intermittent Pleistocene uplift (Huffman, 1958, p. 109).

Following transgression of the Cambrian seas over a hilly to mountainous surface of Precambrian rocks, the Ozark region was an area of carbonate deposition on a fairly shallow warm marine shelf on which some islands of Precambrian rocks remained emergent as late as Early Ordovician time. Silurian and Devonian rocks—limestones, shales, and cherts—were deposited in basins flanking the uplift and may also have been thinly deposited on the older Paleozoic rocks of the uplift. During middle Paleozoic time there was epeirogenic uplift and tilting which resulted in erosion at the end of the Silurian and at the end of the Devonian periods. Mississippian black shales were deposited in deep water over the eroded earlier Palozoic rocks. The succeeding Mississippian fossiliferous limestones, cherts, and black shales indicate continued marine shelf conditions with a limited supply of fine clastics. Broad uplift at the end of the Mississippian was followed by deposition of Pennsylvanian sandstones and fossiliferous limestones with sand and clay more abundant higher in the section. The Atoka sequence is predominantly marine and nonmarine sandstone and shale with thin limestone beds. The post-Atoka beds are shales and coals. During the Pennsylvanian there was an increase in tectonic activity south of the Ozark uplift and an invasion of the earlier shale-limestone marine environment by sands until the entire area was blanketed by sands, probably including the crest of the structure. The post-orogenic Pennsylvanian deposits in the Ozark area were laid down in shallow seas and extensive marine swamps.

Arbuckle Uplift

The Arbuckle uplift trends northwest-southeast in southeastern Oklahoma; its Precambrian and early Paleozoic rocks are exposed in Murray, Pontotoc, and Johnston counties, and it extends southeastward beneath the coastal plain into Atoka, Bryan, and Marshall counties. The uplift has been discussed by Taff (1902, 1903, 1904), Van der Gracht (1931a), Dott (1934), Ham (1955, 1956b), and others.

Precambrian rocks are overlain by a Cambrian through Mississippian sequence which has been divided by Ham (1956b, p. 425) into a southwestern basin province with 12,000 feet of pre-Pennsylvanian sediments and a northwestern shelf province with 7,000 feet of pre-Pennsylvanian sediments. More than two-thirds of the pre-Pennsylvanian rocks are of Ordovician age and are chiefly carbonates. Pennsylvanian rocks which were deposited in the central and northern parts on the site of the pre-Pennsylvanian shelf are about 5,000 feet of marine clastic rocks, including conglomerate, and interbedded limestones; the basin to the southwest (Ardmore basin) received about 17,000 feet of fine-grained Pennsylvanian clastic rocks. This Pennsylvanian basin was more or less congruent with the earlier basin.

Epeirogenic uplift of the northeastern part of the Arbuckle area began early in Middle Pennsylvanian with the rise of the Hunton anticline which was emergent and shed clastic sediments and conglomerates in Middle and Late Pennsylvanian time. Granite fragments in Stanley sandstone southeast of the Arbuckle uplift suggest that possibly there were earlier Mississippian movements of the concealed southeast end of the structure (p. 73).

During the uplift the basin to the southwest continued to subside. Tectonism in this southwestern area was Late Pennsylvanian and was orogenic instead of epeirogenic; the sediments were strongly folded, thrust faulted, and uplifted. The structural uplift was so great that probably 16,000 feet of sediments were stripped from the area (Ham, 1956b, p. 426).

The Arbuckle uplift includes major northwest-trending folds and faults; at least two faults have a strike-slip component of movement (Ham, 1956b, p. 426).

The Arbuckle uplift is a compound epeirogenic and orogenic tectonic element and thus differs from the other frontal uplifts of the Ouachita system. Before Pennsylvanian time the stratigraphic record indicates that it did not differ markedly from other foreland areas except for a thicker sedimentary sequence in the southwestern basin; its deposits included Cambrian sandstones and thick Ordovician carbonates and succeeding Ordovician, Silurian, Devonian, and Mississippian shales, limestones, and sandstones of foreland shelf type. The epeirogenic rise of the northeastern area or Hunton anticline in Middle Pennsylvanian time follows the pattern of other frontal uplifts. An unusual feature was the development of an intracratonic deep trough, the Ardmore basin, south of the Hunton uplift and its subsequent deformation during the Arbuckle orogeny. Deformation in the Arbuckles was of Late Pennsylvanian (Virgil) age according to Ham (1956b, p. 425) and was thus more or less contemporary with the last phases of orogenic activity in the Ouachita Mountains.

Muenster Arch

The Muenster arch is a northwest-southeast-trending uplift that forms the southeast end of the Red River uplift under parts of Denton, Cooke, and Montague counties, Texas, and Jefferson County, Oklahoma (Pl. 2). It is a Paleozoic subsurface feature and is not expressed in the overlying Mesozoic rocks.

On the crest of the uplifted core of the Muenster arch, Precambrian igneous and metasedimentary rocks are overlain directly by Late Pennsylvanian beds which truncate the older Paleozoic rocks (Cambrian, Ordovician—including Simpson and Viola—and Mississippian) still preserved on the flanks. The arch is faulted on the southwest where basement rocks on the northeast or upthrown side are raised about 5,000 feet. The faulting is of post-Mississippian and pre-Canyon (Upper Pennsylvanian) age.

The first Paleozoic movement of the Muenster element is indicated by the shale and sandstone in the Late Mississippian and Early Pennsylvanian deposits adjacent to it—these pass into carbonate rocks and black shale in the basin to the south. Atoka clastics overlap the flanks of the uplift and Strawn sandstones and conglomerates are arkosic on its flanks. Apparently, the Muenster uplift became active in Late Mississippian time and its major positive impulses occurred during Atoka and Strawn time; it was positive and emergent during Early and Middle Pennsylvanian time and shed arkosic clastics southwest and northeast. Upper Pennsylvanian Canyon beds thin over the structure, indicating continued positive tendency but the Cisco shows only a very slight thinning. In some areas the Upper Pennsylvanian lies directly on the Precambrian, showing that disconnected high areas persisted as islands in Middle Pennsylvanian time. Permian beds overlie the Upper Pennsylvanian conformably.

The Muenster arch, which is part of the Red River uplift, was raised in late Paleozoic time; there is no evidence to suggest that it had any positive tendency earlier in the Paleozoic. The Red River uplift may have been controlled by a Precambrian structural trend (Flawn, 1956, pp. 38–39).

Llano Uplift

The Llano uplift of central Texas raises Precambrian and Paleozoic rocks to the surface in Burnet, Llano, Blanco, Gillespie, Mason, Kimble, Menard, McCulloch, and San Saba counties and extends as a structural unit into the subsurface farther north and west. This area was stabilized by profuse granitic intrusions during Precambrian time (Flawn, 1956, pp. 26–27) and at the beginning of Paleozoic time formed a great southern lobe on the North American craton which profoundly influenced subsequent geologic history; it has had intermittent positive tendencies since Precambrian time and acted as a firm buttress against the forces of the Ouachita orogeny. The area is now a topographic basin floored by Precambrian metasedimentary, metaigneous, and igneous rocks and partly surrounded by a rim of Paleozoic rocks that also are downfaulted in grabens within the basin. Along the southern margin is a scarp of Cretaceous rocks.

In the Llano uplift there are about 1,200 feet of Upper Cambrian and Lower Ordovician sediments, mainly sandstone and calcarenite, deposited on a hilly surface with a maximum relief of about 800 feet. A thin remnant of Upper Ordovician limestone is preserved in a collapse structure in the eastern part of the uplift (Barnes, Cloud, and Duncan, 1953), but no Silurian rocks are known. A thin and fragmentary record of once extensive Devonian rocks consisting of dark shales, commonly phosphatic, and local chert breccia is preserved in scattered outcrops mostly along the eastern edge (Cloud, Barnes, and Hass, 1957). The Mississippian is mostly dark shale, commonly phosphatic, and crinoidal limestones generally 40 to 50 feet thick but in some localities more than 100 feet thick. Lowermost Pennsylvanian rocks are mostly dark cherty limestone and dark shale, succeeded by sandstone, shale, conglomerate, and thin limestone of Middle and Upper Pennsylvanian age. The maximum thickness of the Pennsylvanian in the Llano uplife totals about 1,000 feet for the limestone-shale sequence and about 1,400 feet for the overlying clastic rocks.

According to Cloud and Barnes (1957, pp. 194–209), the first Paleozoic sea to invade central Texas submerged a land with considerable relief; the environment was one of moderately deep cool water and abundant available detritus, probably with a number of protruding islands. Toward the end of the Cambrian and the beginning of Ordovician time the waters grew warmer and shallower and shoal conditions prevailed.

> At the beginning of Ordovician time either the Ouachita trough was in existence or the hinterland to the south and east had been reduced to a peneplain—perhaps both (p. 209).

The presence of a channel or trough south and east of the Llano uplift in the Ordovician is indicated by the absence of water-borne detritus in Ellenburger rocks. Evidently, the Llano area was relatively stable in Early Ordovician time, but prior to Simpson time the Ellenburger rocks were truncated (Cloud and Barnes, 1957, p. 209). Before the end of the Ordovician the Llano area was probably uplifted as the south end of the Concho or Texas arch (Cheney and Goss, 1952, pp. 2244, 2262–2263; Adams, 1954, p. 4). There is no record of Silurian history. In Devonian and Mississippian time the Llano uplift area received a thin deposit of dark phosphatic muds, indicative of slow restricted marine sedimentation. The black shales transgress truncated Ordovician carbonates.

Structural movements in the Llano uplift area began in the Lower Pennsylvanian and continued into Middle Pennsylvanian time in response to tectonic activity in the Ouachita mobile belt. Pennsylvanian sedimentation started with limestone and shale on a more or less stable platform. As movements in the geosyncline to the southeast came to a climax, the Llano area was uplifted and block faulted; the flanks were blanketed with sandstone, conglomerate, and shale, with thin limestone in the higher part of the sequence. North- and northeast-trending block faulting occurred during Middle Pennsylvanian (Strawn) time and at some time after Upper Pennsylvanian (Canyon) time the entire area was tilted westward.

Fort Stockton High (Pecos Arch)

The Fort Stockton high, or Pecos arch, is a west-northwest-trending uplift extending through Sutton, Crockett, Terrell, and Pecos counties which forms the northern boundary of the Val Verde basin; it is the southern end of a larger uplift known as the Central Basin Platform.

On its crest Permian beds lie directly on Precambrian rocks (Scobey et al., 1951), but on its steeply dipping or faulted flanks Permian beds truncate Ordovician through Pennsylvanian beds which dip north and south away from the axis of uplift. On the south side Pennsylvanian beds lie unconformably on Ordovician and Devonian rocks and are in turn overstepped by Permian strata; on the north side Permian rocks rest unconformably on the Devonian (Scobey et al., 1951).

The major uplift of the Fort Stockton high occurred in Late Pennsylvanian (post-Virgil) and pre-Permian time (Wolfcamp), but there may have been earlier movements (Adams et al., 1951, p. 2600, fig. 1; P. B. King, 1942, pp. 718–763) as well as later Wolfcamp movements. Whether this block was raised as a horst or whether its high position resulted from downwarp of the basins to the south and north, the Fort Stockton high was positive and emergent in Late Pennsylvanian time. Paleozoic rocks mantling it were stripped off by erosion and the basement was exposed. The Fort Stockton high probably had no pre-Pennsylvanian history as a persistent positive element; it is a late Paleozoic foreland structure.

Devils River Uplift

Wells drilled in southwest Kinney and southeast Val Verde counties and across the Rio Grande in Mexico indicate a structurally high area that appears to trend northwest-southeast; Galley (1958, p. 397) named this the Devils River uplift, but it is also known locally as the Del Rio uplift; its structure has been discussed briefly by Flawn (1959c). There is insufficient well control to delimit the structure accurately, but contours on pre-Mesozoic and Precambrian basement rocks suggest that it is about 100 miles long and 40 miles wide (fig. 2 and p. 172). Plate 2, Section C-C′, shows a schematic northeast-southwest cross section of the Devils River uplift which consists of a mass of Precambrian rocks, apparently mostly metavolcanic rocks, mantled by lower Paleozoic carbonate rocks (Ordovician?). On the south side the Devils River uplift has been overridden by sheared and thrust-faulted low-grade metamorphic rocks of the Ouachita structural belt, and the foreland Paleozoic rocks on the uplift have been sheared and slightly metamorphosed. To the north a clastic sequence of Pennsylvanian rocks thickens rapidly basinward. The Precambrian age of the metavolcanic rocks is indicated by their mantle of lower Paleozoic carbonate rocks and by their lithology, which is not like the metamorphic rocks of the Ouachita belt but resembles late Precambrian metarhyolite exposed in the Van Horn area.

Cretaceous rocks rest on the Paleozoic carbonate rocks and possibly in some areas rest directly on the Precambrian. The uplift may have a mild expression in Cretaceous rocks; Calvert's map (1928, p. 81) shows an anticlinal axis which in part corresponds to the inferred position of the subsurface feature. The sheared and slightly metamorphosed nature of the Paleozoic carbonate rocks overlying the Precambrian suggests that the Devils River uplift played a role in the Ouachita orogeny similar to that of the Llano uplift—a resistant buttress against which the Ouachita system was thrust. Unlike the Llano uplift, the Cretaceous cover of the Devils River uplift was not breached by erosion, although there may have been some post-Cretaceous epeirogenic uplift.

Three wells which disclose the presence of the Devils River uplift are Havoline Oil Company No. 1 Weatherby, Kinney County (p. 284); Richardson Oil Company No. 1 Martin Rose, Kinney County (p. 286); and Hiawatha Oil Company No. 1 Sellars, Val Verde County (p. 322). The concept of the Devils River uplift is based on an interpretation of samples from these wells. The samples are difficult to interpret because they include three types (and probably at least two ages) of sheared metamorphic rocks—(a) an allochthonous sequence of low-grade highly sheared Ouachita rocks including marble, slate, metaquartzite, and phyllite, commonly hematitic, rutiliferous, and graphitic, thrust in from the south and probably Paleozoic in age; (b) an autochthonous sequence of slightly metamorphosed foreland facies Paleozoic carbonate rocks, mostly dolomitic limestone and dolomite, overridden by (a) above and underlain by (c), an autochthonous sequence of sheared metavolcanic rocks of probable Precambrian age.

Present information does not permit detailed reconstruction of the history of the Devils River uplift. The early Paleozoic carbonate sequence suggests that it was a shelf in early Paleozoic time. Whether middle and late Paleozoic rocks were deposited in the area and later stripped off following Pennsylvanian uplift, or whether the area was positive and emergent in middle and late Paleozoic time is a matter for conjecture. In the writer's opinion, the location of the feature and its relations to the Ouachita belt indicate that it is a craton-margin positive element similar to the Llano uplift.

Diablo Platform

The Diablo Platform is a northwest-southeast-trending element in Culberson, Hudspeth, Jeff Davis, Brewster, and Presidio counties, Texas, extending northwestward into New Mexico. The northwestern and southeastern parts are little known and poorly defined, but in the central part (Van Horn area and Sierra Diablo) Precambrian, Ordovician, Silurian, Devonian, and Mississippian rocks truncated by Wolfcamp beds are exposed (P. B. King, 1942, figs. 18, 19; 1949). Strongly deformed and metamorphosed Precambrian rocks are unconformably overlain by about 750 feet of late Precambrian (?) red sandstone, arkose, and conglomerate, which in turn are unconformably overlain by about 1,300 feet of Ordovician strata including a basal sandstone and a succeeding carbonate section. Thin Silurian, Devonian, and Mississippian rocks crop out only on the northeast side of the Sierra Diablo, but there is no indication in their lithology of any nearby shore or land so probably they covered the structure and were later eroded (P. B. King, personal communication, 1959).

The Diablo Platform was intermittently positive. Following late Precambrian orogeny and deposition of post-orogenic late Precambrian (?) rocks (Van Horn sandstone), there was tilting and faulting before transgression of the Ordovician rocks (King and Flawn, 1953, pp. 115–117). Late in the Pennsylvanian, rocks of the Diablo Platform were folded, faulted, and deeply eroded prior to transgression of Wolfcamp beds. Another cycle of emergence, faulting, and erosion occurred after Permian and before Cretaceous time. Ordovician, Permian, and Cretaceous rocks all rest directly on Precambrian in the central part of the uplift (King, *in* P. B. King and Flawn, 1953, p. 97).

It appears that the Diablo Platform extends southward into Presidio and western Brewster counties. Two wells west of the Marathon uplift (Sun Oil Company No. 1 McElroy and Pure Oil Company No. 1 Massie West, both in Brewster County) either passed from Permian beds directly into Devonian and Ordovician or penetrated a relatively thin Pennsylvanian section. Close spacing of the folds and thrust faults in Ouachita facies rocks in the western part of the Marathon Basin suggests that they may have been crowded against a foreland buttress to the west or northwest during the late Paleozoic deformation (p. 166).

Summary

Foreland uplifts marginal to the Ouachita structural belt are of two types: (1) large, more or less domical uplifts with a history of positive tendency throughout the Paleozoic (Ozark and Llano uplifts) and (2) smaller elongate-faulted uplifts of late Paleozoic age (Muenster and Fort Stockton (or Pecos) uplifts). The Devils River and Diablo uplifts are not well enough known for classification.

The large persistently positive features antedate the formation of the Ouachita system; they are old fundamental elements of the North American craton and to a great extent influenced the course of the Paleozoic Ouachita system, which was a craton-margin mobile belt. Faulted uplifts (2, above) probably formed in part as a *response* to the orogenic thrust of the Ouachita belt against the craton. Probably the form and trend of at least the Muenster and Fort Stockton (or Pecos) elements were controlled by Precambrian structural trends, and the Ouachita thrust was resolved along these pre-existing zones of weakness. Although orogenic forces of the Ouachita belt may not have been directly responsible for large foreland uplifts such as the Central Basin Platform, the thrust of the Ouachita system against the craton contributed to the general mobility which existed in the foreland area during the late Paleozoic. The Arbuckle uplift is not solely an epeirogenic uplift—its rocks were deformed and raised during an independent intracratonic orogeny and formed a buttress against the late thrust of the Ouachita orogeny.

Clay Minerals of the Ouachita Structural Belt and Adjacent Foreland

CHARLES E. WEAVER

INTRODUCTION

X-ray studies of shales from the Ouachita structural belt were carried out independently of the petrographic studies made by Flawn and Goldstein. Samples submitted by Flawn and other samples collected by the writer and personnel of the Shell Oil Company were analyzed using standard X-ray methods. The samples were ground to less than 325 mesh, dispersed in water, and allowed to settle on glass slides. The clay minerals were well oriented on nearly all the resulting slides, affording excellent X-ray diffractometer patterns. For many of the foreland samples the less-than-two-micron fraction was separated and oriented on glass slides. The X-ray patterns of these latter samples were little better than those obtained by using the bulk sample. The shale samples had an average composition of approximately 60% clay, 30% quartz, and 10% other minerals.

Clay mineralogy and a new measurement, sharpness ratio (SR), were plotted (figs. 6, 7, 8) to determine the correspondence, if any, between the lithologic, metamorphic, and tectonic divisions of the Ouachita belt mapped by Flawn (Pl. 2) and changes in clay mineralogy and sharpness ratio. It was found that some of the established lithologic units contain distinctive clay mineral suites and that there is a good correspondence between degree of metamorphism determined petrographically and the sharpness ratio determined by X-ray.

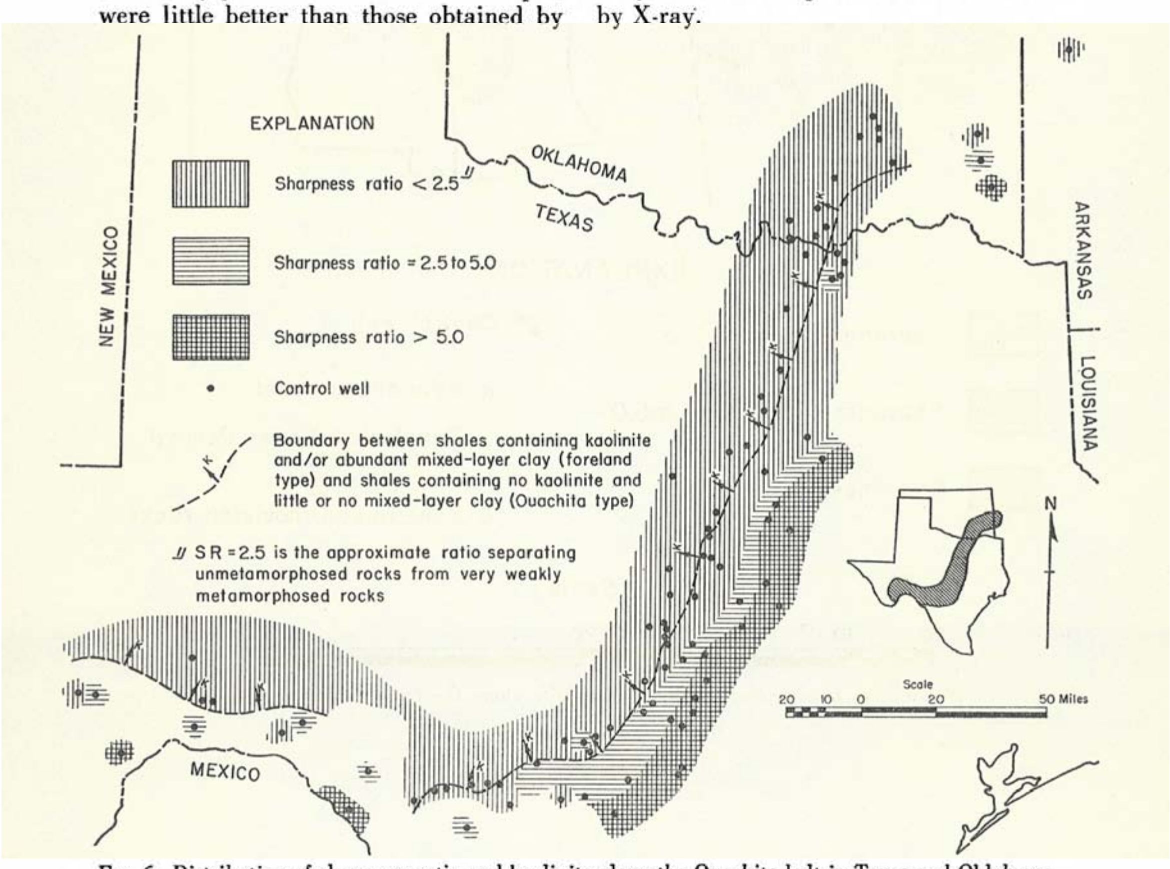


FIG. 6. Distribution of sharpness ratio and kaolinite along the Ouachita belt in Texas and Oklahoma.

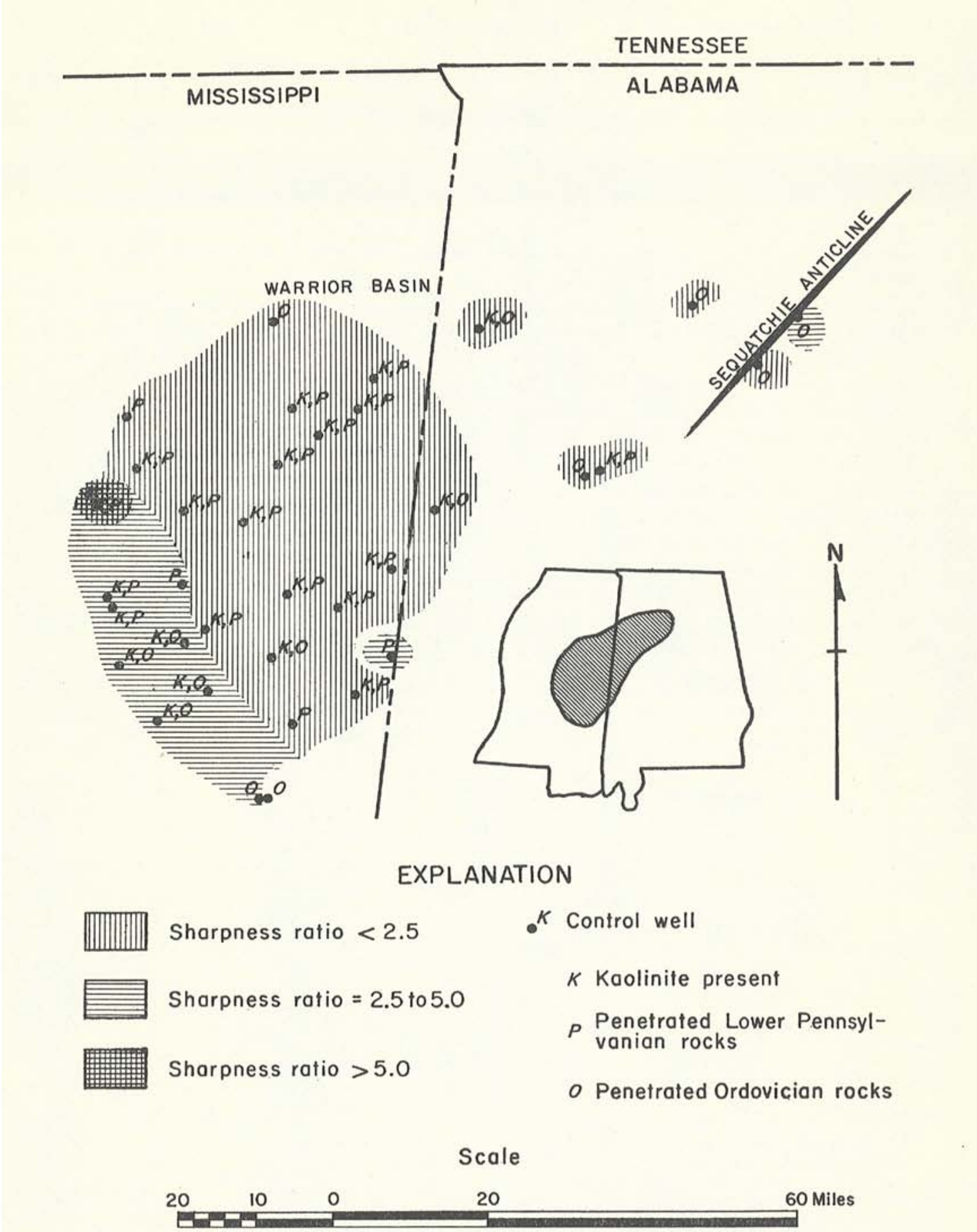


FIG. 7. Distribution of sharpness ratio and kaolinite along the Ouachita belt in Mississippi and Alabama.

Explanation of symbols and ratios.—The following abbreviations are used in this section and pertinent illustrations: K= kaolinite; Ch=chlorite; I=illite; M= montmorillonite; ML=mixed-layer illite-montmorillonite; F = 20 = plagioclase feldspar; F=24=potassium feldspar; SR=sharpness ratio; 10/7=ratio of height of illite X-ray peak (10Å) to the combined (if both are present) chlorite and kaolinite (7Å) X-ray peak. For equal amounts of clay, chlorite and kaolinite commonly afford a 7Å peak approximately 2.5 times as large as the 10Å illite peak. Thus a 10/7 ratio of 2 means that illite is approximately 5 times as abundant as the chlorite and kaolinite combined.

Acknowledgments.—The writer wishes to thank the many Shell Oil Company geologists who have supplied samples for this study and management of Shell and Continental Oil Companies for generously allowing him to participate in this project. Special acknowledgment is made to A. R. Edwards, J. E. Galley, W. S. Pike, F. T. Connolly, and R. G. Stevenson for their help and encouragement in various phases of this work. X-ray analyses were made in the Shell Oil Company's Research Laboratory.

SHARPNESS RATIO

In analyzing X-ray data, the relative sharpness of the illite 10Å reflection appears to be related to the degree of metamorphism as determined by microscopic studies. In general, large flakes and well-crystallized clays afford sharper X-ray reflections than small, poorly crystalline clay minerals. In an attempt to obtain some measure of the relative sharpness of the 10Å peak, a plastic overlay 6.7 inches long with parallel vertical lines representing the 10.0Å and the 10.5Å spacings was placed so that the top of the 10.0Å line coincided with the tip of the 10.0Å illite peak and was perpendicular to the horizontal base of the chart paper; the values from the base of the 10.0Å peak to the point where the 10.5Å vertical line intersected the side of the peak were measured and the total peak height was measured; the ratio of these two values appears to give a reasonable measure of the relative sharpness of the 10.0Å peak (fig. 8). (As the shape of the left-hand side of the 10.0Å peak is relatively constant, it was not necessary to measure values for both sides of the peak and calculate a kurtosis value.)

SR values range from less than 1 in unmetamorphosed foreland facies rocks to more than 12 in metamorphic rocks of the interior zone of the Ouachita belt.

GENERAL REMARKS ON MINERALOGY

Kaolinite occurs in nearly all foreland sediments and is rarely present in Ouachita facies sediments. Illite (70%) and chlorite (30%) together comprise the great bulk of the clay minerals in the sediments studied; the relative abundance of illite and chlorite does not appear to have relation to the degree of metamorphism.

The samples with low SR values contain mixed-layer illite-montmorillonite (predominant ratios 9:1 to 7:3, i.e., 9 parts illite to 1 part montmorillonite). The first detectable effects of regional metamorphism by X-ray diffraction are the removal of the interlayer water from the montmorillonite layers and the reduction of their thickness to near 10Å. Further metamorphism causes increased orientation and an increase in crystal size (Bates, 1947).

The illite in both the Ouachita and foreland rocks and in low-grade metamorphic and unmetamorphosed rocks has a 2M (muscovite-type) structure. The metamorphosed illites, in general, have sharper and stronger reflections in the region from 3.20Å to 2.70Å than do the unmetamorphosed samples.

Many rocks of the Ouachita belt are traversed by veinlets and microveinlets which in some areas contain abundant chlorite (p. 118); thus, X-ray analysis of

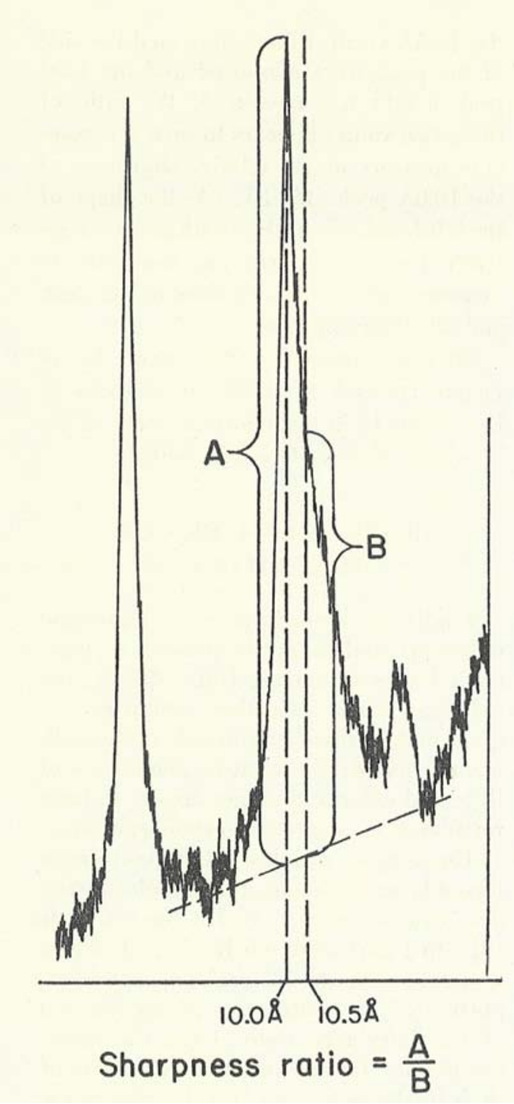


FIG. 8. Method of measuring sharpness ratio.

samples of incipiently to very weakly metamorphosed sedimentary rocks containing abundant vein chlorite might yield results similar to those obtained from analysis of chlorite-rich low-grade metamorphic rocks. Accordingly, vein chlorite and chlorite from metamorphosed and unmetamorphosed rocks were compared.

Oscillating-heating X-ray patterns show that the chlorites from samples of low-grade metamorphic, incipient metamorphic, and unmetamorphosed rocks start to break down (lose hydroxyl water from the brucite layer) at approximately 500° C. Static heating at 500° C. for one hour produced a sharper 14Å X-ray peak for the low-grade metamorphic chlorite. Chlorite samples less metamorphosed than this afforded broad peaks extending from 13Å to 14Å.

The ratio of the height of the 7.1Å to the 4.75Å chlorite peaks ranges from 5 to 7 for the large majority of samples. The same ratio for the vein chlorite is approximately 2. This latter value is in the range usually found for relatively high-grade metamorphic and hydrothermal chlorites. Probably the relative degrees of metamorphism could be determined by a more detailed study of the chlorites.

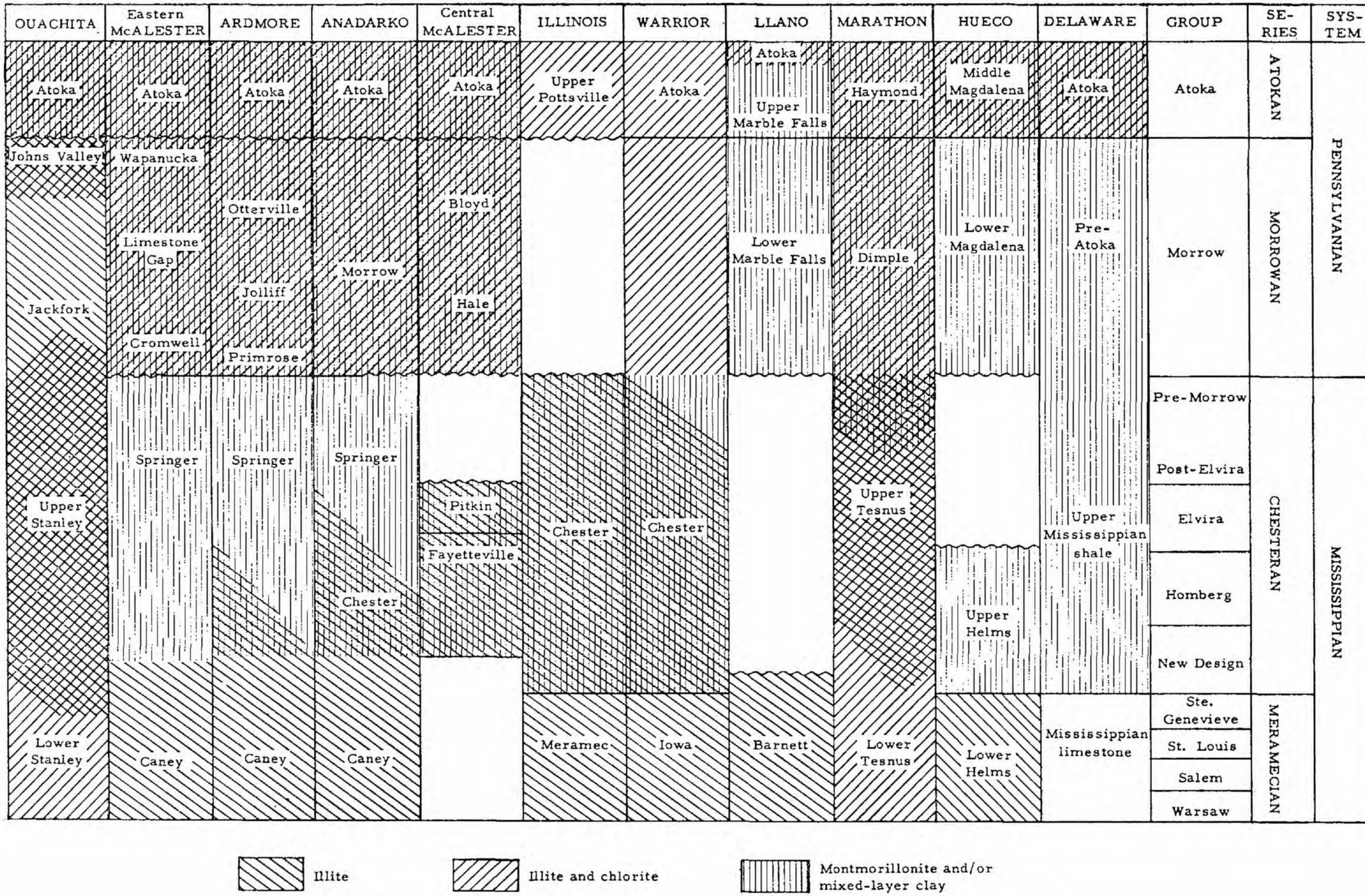


Fig. 9. Distribution of clay facies in Upper Mississippian and Lower Pennsylvanian rocks.

Oklahoma

In Oklahoma, pre-Upper Mississippian sediments generally contain a relatively simple illite-chlorite clay suite, whereas the post-Lower Mississippian sediments usually contain montmorillonite, mixed-layer illite-montmorillonite (and frequently intergrowths of chlorite), and kaolinite in addition to illite and chlorite (fig. 9). This difference is more pronounced in the foreland sediments than in the geosynclinal sediments.

Analysis of approximately 75 outcrop and 25 subsurface samples from the pre-Upper Mississippian rocks of the Ouachita Mountains area indicates that illite is the only clay in approximately 40% of the samples and illite with chlorite occurs in 60%. Most of the samples contain only 5% to 10% chlorite and none contain more than 40%. Kaolinite is relatively minor but occurs scattered throughout the section.

Scattered samples (55) of foreland facies rocks in the Arbuckle Mountains and the Ardmore, Anadarko, and Fort Worth basins resemble those of the geosynclinal facies, although kaolinite is more abundant; mixed-layer illite-montmorillonite (4:1–2:3)[28] is abundant in the Simpson and upper Arbuckle; mixed-layer chlorite-montmorillonite (1:1) is abundant in the upper and middle Arbuckle.

The post-Lower Mississippian formations of Ouachita facies—Stanley, Jackfork, Johns Valley, and Atoka—are similar in composition, being predominantly illite (70%) and chlorite (30%) with minor amounts of kaolinite and mixed-layer illite-montmorillonite. The Stanley sediments generally contain less kaolinite and mixed-layer illite-montmorillonite and more feldspar than the sediments of the three younger formations.

Equivalent formations of foreland facies are the Caney, Chester, Springer, Morrow and Atoka. The Caney is composed predominantly of illite, the Chester and Springer of montmorillonite and/or mixed-layer illite-montmorillonite, and the Morrow and Atoka contain abundant illite and significant amounts of kaolinite, chlorite, and mixed-layer illite-montmorillonite.

The following discussion of the transition between the geosynclinal and foreland sediments is taken from Weaver (1958). Figure 10 is a generalized cross section showing distribution of the major clay mineral facies in southern Oklahoma.

True Ouachita facies sediments in the Ouachita Mountains lie south of the Ti Valley fault (Pl. 2). Between the Ti Valley and Choctaw faults, 2 to 10 miles north, is a series of sediments which is thought by Hendricks et al. (1947) to be transitional between the Ouachita sediments on the south and the Arbuckle sediments on the north. Sediments north of the Choctaw fault are typical Arbuckle facies (foreland facies) sediments.

Outcrop samples were collected from McCurtain County, Oklahoma, in the extreme southern part of the Ouachita Mountains, south of the Ti Valley fault, in the northern part of the Ouachitas, and between the Choctaw and Ti Valley faults.

The lower part of the Stanley in McCurtain County consists of several hundred feet of hard black shale which is overlain by a 90-foot tuff bed. The shale and tuff are of Meramecian age and are generally believed to be the equivalent of the black Caney shales of Arbuckle facies (Hass, 1950). The basal black shale consists of illite and abundant chlorite and kaolinite, the latter being in sharp contrast to the Caney shales which are characterized by a low chlorite and kaolinite content. The gray shale adjacent to the tuff beds contains illite and mixed-layer chlorite-vermiculite, the mixed-layering probably

[28] 4:1 indicates 4 parts illite to 1 part montmorillonite.

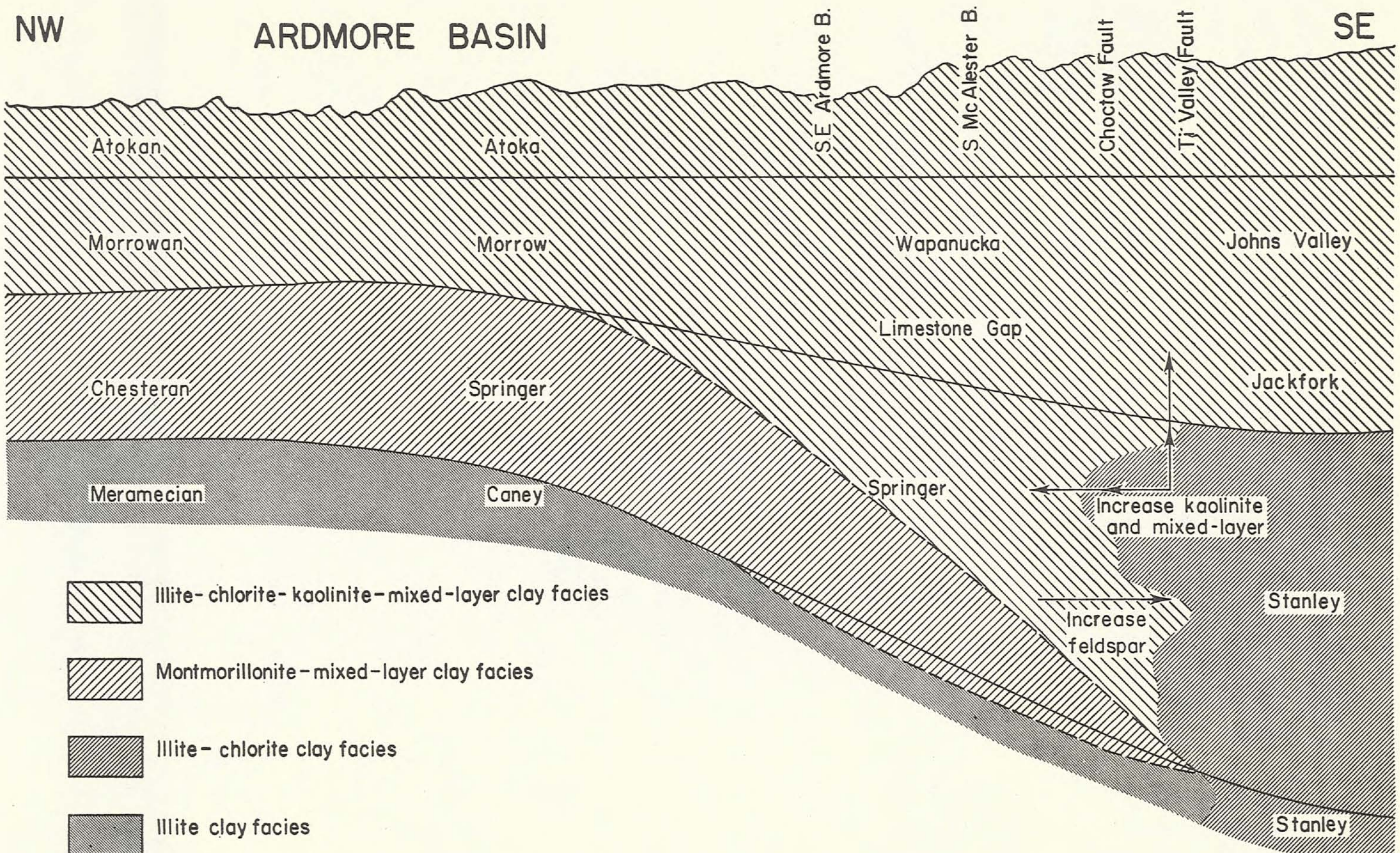


FIG. 10. Generalized cross section showing distribution of clay facies in the Upper Mississippian and Lower Pennsylvanian of southern Oklahoma.

being due to weathering of chlorite. The main tuff bed contains a green, iron-rich 1M[29] illite (glauconite-celadonite); however, several of the thinner beds which have been identified as tuff beds contain well-crystallized 2M illite (muscovite type) which has a Sr-Rb age of 500 million years. The large discrepancy between this age and the Mississippian age of the Stanley suggests that the illite measured is an older detrital mineral and not the product of Mississippian volcanism. The basal black shale a few miles south of the Ti Valley fault (approximately 70 miles northwest of the McCurtain County outcrops) consists of illite and only minor amounts of chlorite and kaolinite; it is more similar to the Caney shales. The gray Stanley shales throughout the rest of the section consist uniformly of varying amounts of illite (2M) and chlorite (weathered to chlorite-vermiculite). In addition to quartz, nearly all the Stanley shale samples contain minor amounts of feldspar. The Jackfork shales contain illite (2M) and mixed-layer illite-montmorillonite and minor amounts of chlorite and kaolinite. The Johns Valley shale is similar to the Jackfork but contains considerably more chlorite and kaolinite, which appear to increase higher in the section. The Atoka shales are similar to the Johns Valley shales but have even more chlorite and kaolinite and resemble the Atoka shales from the Ardmore and Anadarko basins. Montmorillonite-rich shales which occur sporadically throughout the foreland Atoka and Morrow were not found in the Atoka or Jackfork in this area.

Scattered samples taken from between the Choctaw and Ti Valley faults in Hendricks' transitional zone (Hendricks et al., 1947) indicate that their clay mineral content is, in general, similar to that of foreland facies sediments. The Atoka shales are the same as those of foreland facies, and the Wapanucka limestone and associated shales (Morrow) are similar to the Ardmore basin Morrow, that is, the shales are highly micaceous and the bioclastic limestones contain abundant montmorillonite. The lower few hundred feet of Springer and the upper portion of the black Caney shales are montmorillonitic and have a clay-mineral suite similar to the Chester and, somewhat less so, to the Springer shales of the Ardmore and Anadarko basins; either montmorillonite or mixed-layer illite-montmorillonite may be dominant; illite, chlorite, and kaolinite are present in amounts more characteristic of the Chester than the Springer. The lower Caney shales are largely illitic, and although they do not contain any mixed-layer clays they are similar to the Ardmore basin Caney.

At Grants Gap, 10–1S–12E, about one-quarter mile south of the Ti Valley fault, a section of lower Stanley shale was sampled. The lower few hundred feet contains an abundance of montmorillonite and resembles the Springer more than the Stanley; however, chlorite, illite, and feldspar increase upward where the shales are more like typical Stanley shales.

The distribution of the clay minerals in the Springer between the Ti Valley and Choctaw faults and in the southeast Ardmore and southwest McAlester basins indicates that this is the area of transition between the western montmorillonitic facies and the southeastern illitic facies.

Trans-Pecos Texas

The distribution of clay minerals in the Ouachita belt in the Marathon region (fig. 9) is similar to that in the Ouachita Mountains. Analysis of 30 outcrop samples of pre-Upper Mississippian rocks shows that illite is the only clay in approximately 30% of the rocks and illite with chlorite (and often minor mixed-layer illite-montmorillonite) comprises 60%. Mixed-layer illite-montmorillonite is abundant in the Woods Hollow shale and Fort Peña formation (Middle Ordovician). Mixed-layer chlorite-montmorillonite is abundant in the Alsate shale, Marathon limestone (Lower Ordovician), and Dagger Flat for-

[29] 1M = one-layer monoclinic; 2M = two-layer monoclinic.

mation (Upper Cambrian). Small amounts of kaolinite were found in five samples.

Scattered subsurface samples and outcrop samples from the Franklin Mountains and Llano region, in the foreland area, are similar in composition to those examined from the Marathon area.

The Tesnus formation (post-Lower Mississippian) resembles the Stanley. The lower Tesnus shales, in general, contain about 70% illite, 30% chlorite, and possibly minor amounts of kaolinite. The chloritic material is a mixed-layer chlorite-vermiculite (or chlorite-montmorillonite) which is thought to have been formed by the recent weathering of chlorite. As in the Stanley, these lower Tesnus shales grade upward into shales which have an increased illite content. Here the chlorite is more weathered and is actually a vermiculite. The Tesnus shales, like the Stanley shales, also contain feldspar.

Upper Tesnus shales contain, in addition to illite and chlorite, a mixed-layer illite-montmorillonite (7:3) similar to that found in the Chester and Morrow rocks of the foreland. The lower part of the Dimple formation has a similar clay mineral suite. Throughout the remaining Dimple, mixed-layer illite-montmorillonite and/or montmorillonite are dominant and illite and chlorite are only minor. The lower part of the Haymond formation contains illite and lesser amounts of mixed-layer clay, chlorite, and kaolinite.

The Dimple, of probable Morrow age, is mineralogically similar to the lower Magdalena of known Morrow age. The lower Haymond has a typical Atokan suite of clay minerals.

The heavy minerals of montmorillonitic Dimple shales contain about 50% apatite and varying amounts of collophane, zircon, tourmaline, biotite, and rutile. The abundant apatite and biotite indicate that some of these clays were derived from igneous rocks (possibly volcanic material).

In the Hueco Mountains of west Texas, the Meramecian is represented by lower Helms limestone and shales, and the Chester by upper Helms shales and sandy shale. The Helms is overlain by 1,300 feet of Magdalena limestone. The basal beds are of Morrow age and are overlain by approximately 300 feet of Atokan limestones.

The clay suite from the lower Helms consists largely of illite and minor amounts of mixed-layer clay and resembles that of the Caney of Oklahoma and Barnett of central Texas. The upper Helms (Chester) and the lower Magdalena (Morrow) contain similar clay suites composed mostly of mixed-layer illite-montmorillonite (7:3) and a lesser amount of illite. Illite and kaolinite increase upward in the Magdalena section until in the Atoka interval they are generally more abundant than the mixed-layer clay.

Thus, in this area the Chester shales have the high mixed-layer content characteristic of the Chester rocks in general. The Morrow and Atoka clays are similar in composition and sequence to the Morrow (Marble Falls)—Atoka rocks on the southern Bend arch (fig. 11). These Mississippian-Pennsylvanian rocks contain less chlorite and kaolinite than is usual in this interval in other areas.

Farther northeast, in the center of the Delaware basin (Humble Oil & Refining Company No. 1 Federal-Wiggs, 31–24S–27E, Eddy County, New Mexico), Lower Mississippian shale (90 feet), Mississippian limestone (300 feet), Upper Mississippian shale (320 feet), and Lower Pennsylvanian (pre-Atoka?) shale (860 feet) are composed largely of a mixed-layer (7:3) clay of the type found in the upper Helms (Chester) and the lower Magdalena (Morrow). Varying amounts of chlorite, kaolinite, and illite are also present. The Atoka shales consist of interbedded mixed-layer shales and illitic shales. The illitic shales contain considerable chlorite, some mixed-layer clay, and minor amounts of feldspar and are quite similar to the Atoka shales from the southern Fort Worth basin.

The data from this well indicate that both the Meramec and Chester contain

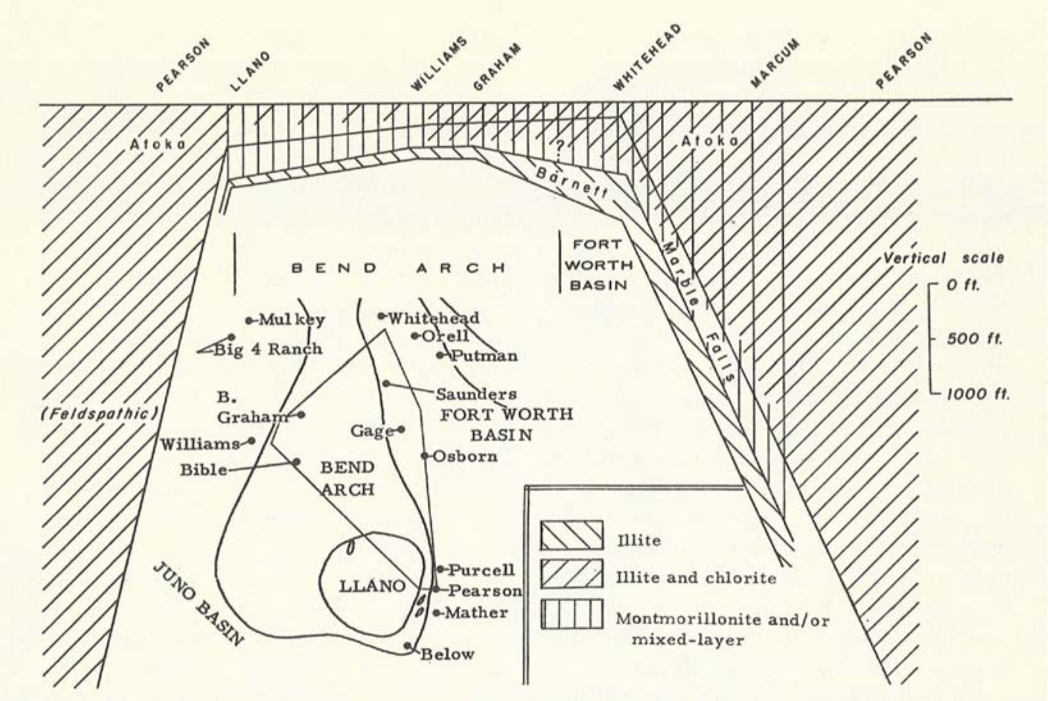


FIG. 11. Generalized cross section showing distribution of clay facies in the Upper Mississippian and Lower Pennsylvanian of central Texas.

mixed-layer-rich shales. The Meramecian(?) shales are quite different from those of the Hueco Mountains and the Mid-Continent region in general. More samples will have to be studied to determine the significance of this difference. The pre-Atoka(?) Pennsylvanian has a clay suite similar to that of the Morrowan rocks from west Texas outcrops.

Farther east on the Central Basin Platform (Sinclair-Prairie Oil and Gas Company No. 1 Campbell, Winkler County, Texas), the Upper Mississippian shale thins to 300 feet. These shales also consist largely of mixed-layer clays, but in general they contain a higher percentage of expanded layers (4:6) than the other Upper Mississippian shales in west Texas. This may indicate a shallower depth of burial. The dominantly illitic (minor amount of mixed-layer clay) Barnett shales have a uniform clay-mineral composition like the Caney shales of Oklahoma. In the Llano region Marble Falls and Atoka clays are largely mixed-layer illite-montmorillonite (7:3) or montmorillonite, though illite, chlorite, and kaolinite occur in some of the Atoka rocks. Mixed-layer clay is abundant in this interval throughout the Bend arch but illite, chlorite, and kaolinite increase in abundance upward and to the north, until in the northern Fort Worth basin they are the dominant clays in the Atoka shales. These shales are identical to the Atoka shales of Oklahoma. In the central portion of the Fort Worth basin an abundance of mixed-layer clay is found in the Marble Falls and lower few hundred feet of Atoka. The upper Atoka shales are similar to those of Oklahoma. A few miles east of the Llano region the Atoka thickens, and the shales are composed largely of illite and chlorite with minor amounts of mixed-layer clay, kaolinite, and feldspar. These shales appear to have been derived largely from the older sediments of the Ouachita structural belt. In general, the mixed-layer clay content of the Atoka increases from south to north in the Fort Worth basin as the foreland Criner Hills source area is approached and increases from north to south on the Bend arch as the southwest Texas foreland source area is approached.

Buried Ouachita Belt In Texas

Only a few pre-Mississippian samples from the belt and adjacent foreland were examined in this area. The clay fraction of the Ellenburger is predominantly mixed-layer illite-montmorillonite and illite. Clay in the Polk Creek shale is almost entirely illite. The Bigfork chert, Missouri Mountain shale, and Arkansas novaculite contain similar clays largely of illite and chlorite with minor amounts of mixed-layer illite-montmorillonite. The clay suites of these formations in subsurface are similar to those of the exposed formations in the Ouachita Mountains.

Clay in the Stanley shale is approximately 60% illite, 30% chlorite, and less than 10% mixed-layer illite-montmorillonite. Feldspar is present in all Stanley shale samples.

The Jackfork resembles the Stanley but generally contains more mixed-layer illite-montmorillonite and no feldspar. The Atoka is also like the Stanley, though most samples contain more mixed-layer illite-montmorillonite. Feldspar is usually present. The Atoka contains kaolinite (less than 5% to 10%) which distinguishes it from the Stanley and Jackfork. The line marking the appearance of kaolinite (fig. 6) in most places coincides with the foreland facies—Ouachita facies boundary (Pl. 2).

In southern Kendall and Blanco counties there are three wells (J. S. Abercrombie and Harrison Oil Company No. 1 Lena Kunz and Joe Nickel; Clarence Newton No. 1 Check Ranch; and Theodore Hicks No. 1 Albert Specht) wherein shales contain from 20% to 30% kaolinite. This is a much higher kaolinite content than was observed in other shale samples in the Ouachita belt and may reflect the presence of a local granitic source to the south (p. 76). Flawn (Pl. 1) places these wells in the Ouachita structural belt, but the relatively high content of mixed-layer clay suggests that they might be transitional or foreland facies sediments.

Some of the low-grade metamorphic rocks (Texas Gulf Sulphur Company No. 1 Baker, Milam County; Rimrock-Tidelands, Inc., No. 1 W. F. Crawford, Milam County; Humble Oil & Refining Company No. 1 M. Holderman, Hill County; Clarence Newton No. 1 Check Ranch, Kendall County; and Anderson-Prichard Oil Corporation No. 1 E. H. Yturri, Bexar County) contain appreciable amounts of kaolinite.

Southern Appalachians, Black Warrior Basin, and Buried Eastern Segment of the Ouachita Belt

Seven hundred fifty samples representing 50 formations of pre-Upper Mississippian rocks of the southern Appalachians indicate that illite is the only clay in approximately 30% of the samples; 60% contain both illite and chlorite; 10% are composed predominantly of mixed-layer illite-montmorillonite and chlorite-montmorillonite. Sixty percent of the samples containing illite and chlorite contain from less than 5% to 10% chlorite, and about 20% contain more than 20% chlorite. Kaolinite is present in approximately 5% of the samples, generally in amounts less than 20%.

The clay suite of the pre-Upper Mississippian rocks of the Black Warrior basin (13 wells) is similar to that in the Arbuckle Mountains and the west Texas area. Illite and chlorite predominate (with illite being by far the most abundant); mixed-layer illite-montmorillonite is relatively common as an accessory. Mixed-layer chlorite-montmorillonite is abundant and frequently dominant through much of the Lower Ordovician Knox. Ordovician carbonate rocks along the northeastern border of the Ouachita structural belt contain clay suites similar to those of the Ordovician carbonate rocks in the center of the Black Warrior basin.

Samples of the Upper Mississippian

Mauch Chunk shale from the Appalachian Mountains in central Pennsylvania are composed of illite and a slightly lesser amount of chlorite and are similar in composition to the Stanley and Tesnus shales.

Post-Lower Mississippian samples were examined from 10 wells from near the center of the Black Warrior basin (fig. 9). The residues from the Meramecian limestones consist predominantly of illite with minor amounts of chlorite. The clay-mineral suite resembles that in the Meramecian limestones of the Illinois basin and the black Caney shales of Oklahoma and Texas. The lower half of the Chester section[30] contains shales which have approximately 30% chlorite and kaolinite and 70% illite and mixed-layer illite-montmorillonite, the latter, which has a 7:3 ratio, being two to four times as abundant as the illite. The clay-mineral suite of these shales is similar to that of the Chester shales of Illinois but, in general, contains less mixed-layer clay than the Chester shales of Arkansas and Oklahoma. The upper Chester shales and the overlying Pennsylvanian Morrow-Atoka shales consist largely of illite, chlorite, and kaolinite and contain only minor amounts of mixed-layer clay. These Morrow-Atoka shales have less mixed-layer clay than those from Oklahoma and are similar to those of the Illinois basin. The change in clay-mineral composition which occurs within the upper Chester section is similar, though less pronounced, to that which occurs between the Mississippian and Pennsylvanian rocks of Oklahoma, Arkansas, Texas, and the Illinois basin. This could mean a Pennsylvanian age (Morrowan?) for the upper Chester or that orogenic movement (change of source) occurred earlier in the Black Warrior basin.

The few outcrop samples examined of Parkwood, Pennington, and Floyd shale suggest a sequence of clay-mineral suites similar to the subsurface well samples. The lower Chester Floyd formation has considerable mixed-layer clay, whereas the geosynclinal upper Chester Pennington and Mississippian-Pennsylvanian Parkwood formations are composed largely of illite, chlorite (mixed-layer chlorite-vermiculite), and kaolinite.

[30] Based on the Chester "top" currently in use by subsurface geologists in the area.

METAMORPHISM

Figure 6 shows the distribution of sharpness ratio values in the Ouachita structural belt.

The highest grade of metamorphic rocks outcropping in the Ouachita Mountains is in the southern portion of McCurtain County, Oklahoma. Samples from outcrops range in age from the Upper Cambrian (?) Lukfata to Upper Mississippian Stanley. The regional metamorphism is variable, ranging from incipient to low grade. The sharpness ratio values in the McCurtain County area range from 4 to 10, averaging approximately 6 (the average for the Stanley is 8). Illite-rich samples from the pre-Upper Mississippian rocks of foreland facies have an average sharpness ratio of approximately 3.

Stanley samples from outcrops slightly northwest of the area of maximum metamorphism have an average sharpness value of 4.3. Farther to the north in the vicinity of the Choctaw and Ti Valley faults, outcrop and subsurface samples of the Stanley, Jackfork, and Atoka have values of less than 2. Sharpness values for samples in the foreland facies of the Ardmore basin range from less than 1 to 1.8.

The distribution of sharpness ratios shown in figure 6 is based on average values obtained on the same bulk samples that were examined under the petrographic microscope by Flawn. Most values represent an average of several samples (2 to 15). Most of the values greater than 5 fall in the region of low-grade metamorphism. Most of the values between 2.5 and 5 are in the region of incipient to weak metamorphism. Values less than 2.5 occur in the area of no metamorphism. The latter include rocks of both foreland and Ouachita facies; however, in most instances, the presence or absence of kaolinite serves to distinguish between the two facies. Table 7 lists the average SR values for the metamorphic zones in the subsurface Ouachita belt in Texas (all data are from X-ray patterns of bulk samples). Questionable values were omitted; for example, samples from Korshoj No. 1 Simon-Ferguson in McLennan County which were classed petrographically as showing incipient to very weak metamorphism have an SR of 9.0, which is several times larger than the SR value of the other samples in the same class. This anomalous ratio may be the result of contamination.

TABLE 7. *Average sharpness ratios in rocks of the subsurface Ouachita belt in Texas.*

	Average SR
Low-grade metamorphism	12.1
Weak to very weak metamorphism	6.3
Incipient to weak metamorphism	4.5
Incipient metamorphism	2.3
Unmetamorphosed Stanley	2.3
Unmetamorphosed Atoka	1.8

Figure 7 is a plot of the SR values obtained on the less-than-2-micron fraction of Paleozoic samples from wells near the margin of the buried eastern segment of the Ouachita structural belt. Ordovician illites from the center of the Black Warrior basin and east of the Ouachita structural belt have an average SR value of 2.0; those samples from wells in the southwestern portion of the basin close to the Ouachita belt have an average value of 3.5.

Lower Pennsylvanian shales near the center of the Black Warrior basin have an average SR value of 1.9.

SR values near the western edge of the basin range from 3.5 to 8.0 and average 5.25. If the data obtained from the Texas segment are extended to this area, the one well with an SR value of 8 (The Texas Company No. 1 Whitehead) is the only one which is within the range of values representative of low-grade metamorphism. The other high values are in the range of incipient to weak metamorphism. Kaolinite is present in most wells, suggesting that rocks in the frontal zone of the Ouachita belt in this area may be of foreland facies.

Several distinctive clay mineral suites appear to have regional distribution (fig. 12). A zone of mixed-layer chlorite-montmorillonite (whose mineralogy and chemistry have been discussed previously (Bradley and Weaver, 1956)) occurs in the Upper and Lower Ordovician and can be traced from the western portion of the southern Appalachians to the Franklin Mountains of extreme west Texas. This mixed-layer chlorite-montmorillonite zone extends from slightly above the top of the Cambrian to slightly below the base of the Chazyan (Arbuckle-Knox-Ellenburger). There is little clue to the origin of this relatively rare type of clay; it is likely that the clay was originally a montmorillonite and that layers of brucite were precipitated between approximately half the layers. The montmorillonite may have been formed from volcanic material, weathered chlorite, and/or weathered illite. The absence of diagnostic heavy minerals of volcanic origin and the fact that the montmorillonite-like layers appear to have a relatively high tetrahedral charge (LiCl treatment[31] (Greene-Kelly, 1955) indicates that the expanded layers have a predominantly tetrahedral rather than an octahedral charge) suggest that the clay was more apt to have been derived by the leaching of potassium from micas and illite and/or the leaching of brucite from chlorite. Expanded clays (montmorillonite, vermiculite, mixed-layer chlorite-montmorillonite, and chlorite-vermiculite) are the common weathering products of illite and chlorite in instances where leaching is not thorough enough to form kaolin-like minerals.

During Middle Ordovician time (Black River) periodic volcanism occurred which resulted in the formation of at least 14 separate ash falls in the eastern United States. The volcanic material was altered and preserved as a mixed-layer illite-montmorillonite (7:3) (Weaver, 1953). These "K-bentonite" beds have been traced as far west as Minnesota and as far south as Alabama. Discrete ash beds do not appear to have been preserved in the Oklahoma and Texas sediments; however, abnormally abundant mixed-layer illite-montmorillonite exists in the Simpson of Oklahoma and the Woods Hollow and Fort Peña formations of the Marathon area.

A montmorillonite zone of regional extent occurs in Upper Mississippian rocks. This zone can be traced all through the eastern and central United States and at least as far west as Nevada. The montmorillonite and/or mixed-layer illite-montmorillonite commonly comprise 40% to 80% of the clay suite. Figure 9 shows the approximate top and bottom of this zone in the basins flanking the Ouachita structural belt.

The clay zone underlying this montmorillonite zone is composed predominantly of illite, perhaps averaging as high as 90% in most foreland formations. The clay suite overlying the montmorillonite zone is, in nearly all areas, a complex suite containing illite (approximately 50%), mixed-layer illite-montmorillonite, chlorite, and kaolinite (Weaver, 1959). This latter clay suite is believed to have been derived largely from source areas to the east and south, and the mineralogic change between the montmorillonite zone and the overlying complex clay suite is believed to reflect orogenic uplift in the Appalachian and Ouachita structural belts. It is interesting to note that in the Black Warrior basin this mineralogic break occurs within the Chesteran (*see* footnote 30, p. 158), in Oklahoma near the end of Chesteran, and in west Texas in the Lower Pennsylvanian. This suggests that the tectonic activity responsible for the change in clay mineralogy occurred later in the western area.

In the Black Warrior basin, the Knox, Wells Creek, and Stones River formations

[31] If expanded clays are saturated with LiCl and heated at 200° to 300° C. for 24 hours, the Li is believed to migrate into the vacant octahedral sites and nullify the octahedral charge. If the clay originally had a predominantly octahedral charge, after treatment the clay will not expand and will resemble talc. If the original charge was predominantly tetrahedral, the clay will continue to expand after treatment.

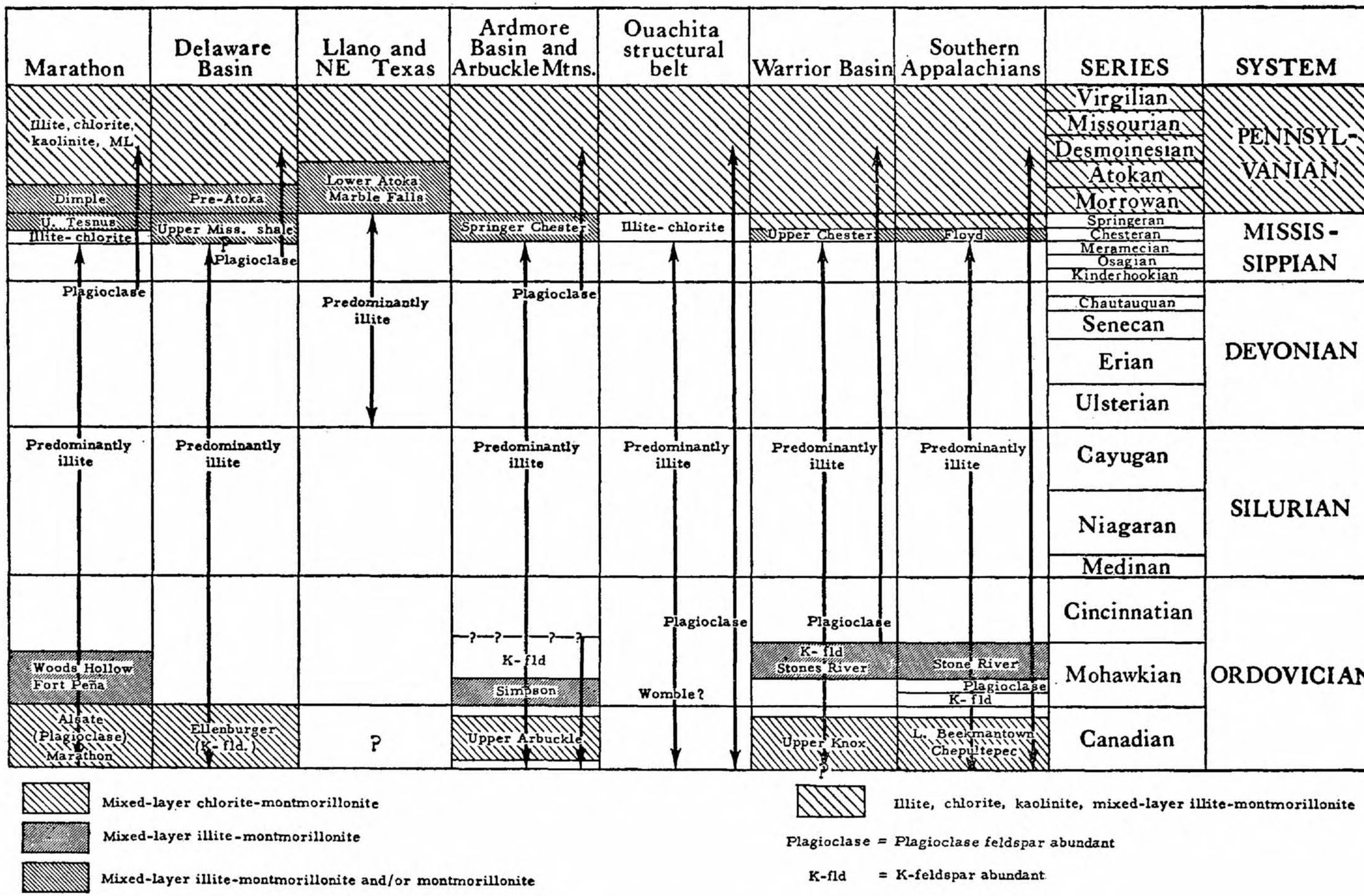


FIG. 12. Generalized correlation chart for clay-mineral zones.

contain predominantly potassium feldspar and the overlying rocks of Trenton age, predominantly a plagioclase feldspar. An examination of Ordovician samples indicates that this change in the type of feldspar is of regional extent. Upper Cambrian and Lower Ordovician outcrop samples from the southern Appalachians (Tennessee and Virginia) and from central Pennsylvania contain predominantly potassium feldspar, and samples from Upper and upper Middle Ordovician contain plagioclase. Sufficient samples were not available to determine the exact position of the boundary.

Scattered samples from the Lower Ordovician El Paso-Ellenburger of west Texas all contain potassium feldspar. Samples from the overlying Montoya were not available. In the Arbuckle Mountains of southeastern Oklahoma, potassium feldspar is found in the Arbuckle, Simpson, and Viola formations. It is much more abundant in the Arbuckle than in the other two formations.

X-ray analysis of slate, phyllite, and schist samples from the southern Appalachians and northern Mexico shows that plagioclase is the dominant and usually the only feldspar. It seems quite plausible that much of the plagioclase feldspar in the Middle and Upper Ordovician was derived from this eastern and southern metasedimentary source.

The outcropping early Paleozoic Ouachita Mountain sediments are predominantly clastic sediments. This detritus was apparently derived from a metasedimentary source to the south. Thus, the Upper Cambrian and Ordovician sediments of the Ouachita Mountains are presumably more similar to the sediments which comprised the eastern part of the Appalachian geosyncline. X-ray analysis of Ouachita samples indicates that plagioclase is the dominant and usually the only feldspar present in these early Paleozoic rocks (extending from the Upper Cambrian Lukfata formation through the Lower Pennsylvanian Atoka). In the Marathon region, early Paleozoic rocks contain potassium feldspar and plagioclase.

These data suggest that detrital feldspar in the early Paleozoic was derived from two major types of source rocks, probably granitic rocks in the interior shield and metasedimentary rocks from an area which was located east or southwest of the present Appalachian and Ouachita Mountains. The distribution of the two types of feldspar may be a function of the relative effectiveness of these two areas in supplying detritus to the basin of deposition. Possibly the feldspars could be used to distinguish between pre-Middle Ordovician Ouachita and foreland facies sediments.

Tectonics

PETER T. FLAWN

General Statement

The maps (Pls. 1, 2, and 3) show the Ouachita belt as a narrow band extending from southwest Alabama into Mexico. In most segments the Ouachita front or side toward the North American craton or foreland is rather well defined. The southeastern limit of the belt as shown on Plate 1 is not a boundary but merely the down-dip limit of well control. Therefore, the apparent narrowness of the belt is an illusion and merely indicates lack of data. Widths of the belt measured across the two major salients (Ouachita Mountains and Marathon uplift) from the structural front to the down-dip limit of well control are 90 and 70 miles, respectively, but these distances are not actual widths. The known length of the belt in the United States is at least 1,300 miles, and it may extend southward into Mexico for at least 300 miles. These minimum dimensions show that the Ouachita belt ranks with the Appalachian belt in order of magnitude and is a major continental structural feature.

The front of the Ouachita belt as mapped is strongly sinuous, curving toward and over the craton in broad salients and recessed around massifs or buttressing elements along the craton margin; the salients of the belt perhaps mark the position of "bays" in the old craton where the craton margin subsided deeply during formation of the Ouachita geosyncline or during orogeny. The course of the Ouachita front as it exists today was strongly modified by the behavior under stress of tectonic elements on the margin of the old craton; the course of the pre-existing Ouachita geosyncline was determined by the margin of the old craton as it was before the orogeny.

BASIS FOR SUBDIVISION

Theoretical Considerations

During recent decades the accumulation of geologic and geographical data on orogenic belts over the world has led to a much better understanding of their origin and development. Many modern ideas are summarized in a recent symposium volume, *Crust of the Earth* (Poldervaart, 1955). In a synthesis of data available on the western Alps and southern Appalachian deformed belts, Bucher (1955) stated that in these typical belts there are three major structural zones between foreland and hinterland: (1) an outer belt of shallow folds and thrusting, (2) a marginal belt of piled-up thrusts and nappes, and (3) a belt of crustal folds involving metamorphic and plutonic rocks. In the outer zone, the deformation is mainly surficial and does not involve the basement; in the marginal zone the thrust masses are allochthonous plates which may be detached from their original base (Bucher, 1955, pp. 348, 351, 353, 356). In the southern Appalachians the outer zone of shallow folds and thrusting corresponds to the Valley and Ridge structural province, the interior marginal zone of piled-up thrusts corresponds to the northwestern part of the Blue Ridge structural province, and the belt of crustal folds of metamorphic and plutonic rocks takes in the Piedmont structural province and the southeastern part of the Blue Ridge province.

Boundaries between the three main subdivisions of a typical orogenic belt are not everywhere sharply defined and in many places passage from one province to another is marked only by a general change in the structural grain or occurs within a rather broad zone. P. B. King (1950, pp. 646–647) comments as follows regarding the boundary between the Valley and Ridge province and the Blue Ridge province in the southern Appalachians:

> Along a line somewhere in the southeastern part of the Valley and Ridge province, a change takes place in the mode of deformation. This change in structural habit is well illustrated by recent work of Cloos . . . in South Mountain, Maryland. . . . The folds northwest of South Mountain are flexure folds in which the strata are merely bent, the distortion being taken up by gliding between the beds . . .; cleavage and other metamorphic effects are nearly lacking. By contrast, the folds in South Mountain are shear folds, in which the whole mass of stratified rocks, and the underlying basement as well, were deformed as a unit by laminar flow, resulting in extensive development of slaty cleavage, and in marked tectonic thickening of strata along the axes of the folds.
>
> The present writer [King] believes that this change in structural habit, as much as any other character, serves to separate the Valley and Ridge province from the Blue Ridge province, next on the southeast.
>
> Many geologists have believed that the Valley and Ridge province is separated from the Blue Ridge province by a *continuous* low-angle thrust fault, or faults, styled the 'Blue Ridge overthrust' . . .; but faulting along the boundary is actually discontinuous. . . .
>
> In some places, low-angle thrust faults along the boundary between the two provinces are strikingly developed, for example, throughout the segment in Tennessee. . . . Here, the Great Smoky thrust and Holston Mountain thrust have carried the rocks of the Blue Ridge province northwestward over those in the Valley and Ridge province, and many windows reveal the overridden rocks for as much as 35 miles behind the northwestern boundary of the province. . . . The low-angle thrust faults in Tennessee, like the folds in South Mountain, Maryland, extend into the basement rocks, and thus differ fundamentally from those in the Valley and Ridge province.

Farther southeast in the Appalachian belt, the boundary between the metamorphic and plutonic rocks of the core of the orogenic belt and the Blue Ridge tectonic province is indefinite and includes an apparently transitional zone (P. B. King, 1950, p. 650). According to Bucher (1955, p. 360) the belt of metamorphic and plutonic rocks in the southern Appalachians includes the southeastern half of the Blue Ridge province (the physiographic Blue Ridge province) and most of the Piedmont province, and fades out southeastward into a less-metamorphosed and less-deformed "hinterland."

The tectonic analysis of the Ouachita belt which follows draws heavily on the general analysis of orogenic belts made by Bucher (1955) and specifically on the synthesis of P. B. King in the southern Appalachians (1950, 1955a, 1955b). Interpretations of tectonic relations in the poorly exposed Ouachita belt are in large part interpretations by analogy with more completely exposed and studied orogenic belts elsewhere, in particular with the southern Appalachians.

Rocks of the Ouachita Belt

Rocks of the Ouachita belt fall into two broad groups: (1) unmetamorphosed to very weakly metamorphosed sedimentary rocks showing the effects of strong deformation but without any pronounced directional fabric and (2) sedimentary rocks showing weak to low-grade metamorphism with a high shearing component and the metamorphic structures associated with high shear (foliation, slaty cleavage, fracture cleavage, wrinkling, rucking, microimbricate structures, flowage around augen); sheared and altered igneous rocks make up a minor part of this group. Rocks transitional between these two major groups are relatively scarce.

The two major petrographic groups form long belts parallel to the general strike of the Ouachita structural belt (Pls. 1 and 2); group (1), composed of unmetamorphosed to very weakly metamorphosed sedimentary rocks, forms a belt bordering the foreland, and group (2), composed of highly sheared rocks showing weak to low-grade metamorphism, forms an interior belt to the south and east of the rocks of group (1). Transitional rocks, where present, are in a zone along the boundary of the two major rock groups or occur within the area of group (1) in zones of strong deformation (p. 122). The belt of rocks adjacent to the foreland is the *frontal zone* of the Ouachita belt, and the belt of rocks lying south and east of the frontal zone is the *interior zone* of the Ouachita belt; the frontal zone has known limits on both sides, but the less known interior zone is recognized only in a relatively narrow strip along the southeast side of the frontal zone (Pls. 5–15).

THE FRONTAL ZONE[32]

General remarks.—Rocks and structures of the frontal zone of the Ouachita belt are exposed in the Ouachita Mountains and Marathon salients of the Ouachita belt and include the Solitario and Persimmon Gap areas in Trans-Pecos Texas and a small outcrop near Turkey Bend of Lake Travis in central Texas. The Ouachita Mountains of Oklahoma and Arkansas constitute by far the largest exposure, but heavy vegetation and soil cover obscure the relations in much of the area; in Trans-Pecos Texas and especially in the Marathon region the structure of the frontal zone of the Ouachita belt is exposed in wonderful clarity. In both the Ouachita Mountains and Marathon areas the Paleozoic rocks are strongly folded; the folds are commonly overturned toward the foreland and are broken by thrust faults, reverse faults, and tear faults, and the older thrust faults are folded. In both areas the structure is of Appalachian type and has been interpreted as the product of several orogenic periods or intermittent orogenic pulses extending through a considerable span of late Paleozoic time.

MAJOR STRUCTURES OF THE SALIENTS

The structures in the Marathon Basin consist of two northeast-southwest-trending anticlinoria separated by a synclinorium (P. B. King, 1937); from northwest to southeast these are named the Marathon anticlinorium, the Peña Colorado synclinorium, and the Dagger Flat anticlinorium. These features occur in the uplifted western part of the area; to the northeast is a depressed area. The two doubly-plunging anticlinoria expose lower Paleozoic rocks. The northwest side of the Marathon anticlinorium was ruptured by the Dugout Creek overthrust, along which the rocks of the Ouachita belt have been displaced over the foreland for a distance of at least 8 miles. According to estimates by P. B. King (1937, p. 131), the minimum amount of crustal shortening as a result of deformation in the Marathon area is 15 miles and probably it is considerably more. Only part of the salient is exposed in the Marathon Basin, and other anticlinoria probably occur in the concealed part farther southeast (Pl. 2); a third anticlinorium southeast of and more or less parallel to the Dagger Flat anticlinorium probably includes the lower Paleozoic exposures of the Jones ranch and Persimmon Gap areas, and perhaps part of another such feature is exposed in the Solitario. In the subcrop in southern Terrell County, slightly metamorphosed lower Paleozoic rocks indicate an uplifted area of the frontal zone. Synclinoria probably occur between these concealed anticlinoria.

In the Marathon salient, then, a series of complexly faulted anticlinoria have raised the older lower Paleozoic rocks and these have been locally thrust over younger rocks—in Terrell County very weak metamorphism seems to be associated with the uplifted structure. Beds as young as Atoka in age are preserved in the depressed structures.

In the Ouachita Mountains salient the major structures are: (1) A large central anticlinorium, trending east-west in the eastern part of the area and northeast-southwest in the western part, which reflects the trend and shape of the entire salient; this includes the large uplift in Montgomery, Garland, and Saline counties, Arkansas, and the so-called "core" of the Ouachita Mountains in McCurtain County, Oklahoma (Pitt, 1955); recently this anticlinorium has been called the Broken Bow–

[32] Not to be confused with Hendricks' "frontal belt of the Ouachita Mountains" which refers to the area of the Ouachita Mountains lying between the Choctaw and Ti Valley faults (Hendricks, 1943 and subsequent publications).

Benton uplift (Miser, 1959). (2) A thrust-faulted synclinorium north and northwest of the Broken Bow–Benton anticlinorium which includes the complexly thrust-faulted frontal belt of the Ouachitas studied by Hendricks (Hendricks et al., 1947); in it, older rocks come to the surface in the Potato Hills and at Black Knob Ridge. (3) A synclinorial area which lies south of the Broken Bow–Benton uplift, largely in Arkansas.

The minimum amount of movement on the faults in the frontal belt of the mountains seems to be in excess of 50 miles (Hendricks, 1959, pp. 48–50); the rocks south of the Ti Valley fault probably have been thrust north-northwestward for a distance of 20 or more miles (Miser, 1934c, p. 1065; 1959, p. 32), and there may have been a total minimum shortening of 70 miles in Oklahoma and 50 miles in Arkansas (Miser, 1929, p. 12). The youngest beds preserved in the synclinoria in the Ouachita Mountains are part of the Atoka formation.

The two structural salients of the Ouachita belt show many interesting similarities:

(1) The frontal zone is broad and has Appalachian-type structure; major structural axes are convex toward the foreland.

(2) The western part of each salient impinges on a foreland buttressing element with pronounced thrust faulting; in the Ouachita Mountains salient this buttress is the Arbuckle element; in the Marathon salient the buttress is the southeastern extension of the Diablo Platform. In both salients folds are the dominant structures in the eastern part.

(3) Major anticlinoria and synclinoria whose axes parallel the trend of the belt occur in both salients; the anticlinoria have raised lower Paleozoic rocks into the outcrop or subcrop, whereas beds as young as Atoka occur in the synclinoria.

(4) Rocks along the axes of the anticlinoria have been metamorphosed in parts of both areas—in the Ouachita Mountains salient along the Broken Bow–Benton anticlinorium in what was probably the most deeply buried part of the salient and in the Marathon salient in the concealed southern Terrell County structure.

The major differences between the two areas are in structural scale (P. B. King, 1937, p. 134) as the amplitude of the Marathon salient structures is considerably less than in the Ouachita Mountains. Metamorphism was also more intense and extensive in the Ouachita Mountains salient. This may indicate that deformation of the Ouachita Mountains salient occurred under a much thicker cover than deformation in the Marathon region (P. B. King, 1937, p. 134).

Concealed Frontal Zone of the Ouachita Belt Between the Salients

South of the Ouachita Mountains salient, between Dallas and Uvalde counties, Texas, the frontal zone is narrower than in either the Ouachita Mountains or Marathon salients. Although there are minor sinuosities in the course of the front, there are no major bulges or convexities. This segment of the Ouachita belt can be called the Llano recess because the Llano buttress here dominates the path of the deformed belt. In the frontal zone are Stanley and pre-Stanley rocks of Ouachita facies and narrow belts of foreland rocks of Morrow and Atoka ages that were involved in the deformation against the Llano buttress. Pre-Stanley rocks occur in subcrop along the front of the belt along faults or faulted folds. In northeastern Williamson County pre-Stanley rocks form the subcrop farther southeast in the frontal zone, perhaps in an anticline. In the southeastern part of the frontal zone the subcrop is a lithologic unit of unknown age which may be a near-source facies of the early Paleozoic rocks; if so, there is a major uplift in the interior part of the frontal zone (p. 78).

From scattered cores and from microstructures seen in thin section, it is evident that the over-all structure in the frontal zone of the belt in this area is much like that in the exposed parts of the salients—

the beds are steeply dipping and have been fractured, slickensided, and cut by numerous veins.

The only major structures that can be discerned in the frontal zone in this segment of the belt are frontal thrusts, suggested by the juxtaposition of Ordovician Ouachita facies rocks and foreland facies Pennsylvanian rocks in the subcrop and locally proved by wells which drilled through the dislocated Ouachita plates into underlying foreland facies rocks (Pl. 2). In McLennan and Coryell counties there is more than 5,000 feet difference in altitude between the top of the Bigfork in St. Louis Oil Pool Company No. 1 Ella V. Stuart (Stewart) and the top of the Bigfork in General Crude Oil Company No. 1 Earnest Day about 5 miles away. A major structure thus occurs in this area, and many other such structures probably occur elsewhere in the area.

The frontal zone of the belt in Uvalde and western Medina counties is little known and poorly defined. Here several wells have penetrated Mississippian - Pennsylvanian rocks characteristic of the frontal zone, but control is inadequate to determine trend.

In Kinney and Val Verde counties, the frontal zone, which is continuously and broadly developed to the east and west, disappears abruptly, and a change in the trend and character of the Ouachita belt is indicated. The area of disappearance of the frontal zone coincides with a concealed area of high-standing Precambrian rocks —the Devils River uplift. Two hypotheses may account for the missing frontal zone: (1) The Ouachita geosyncline formed south of the area of the Devils River uplift and the frontal zone developed in that area; subsequently, the rocks of the frontal zone were completely overridden by the metamorphosed rocks of the interior zone. (2) Because of the area of high-standing Precambrian rocks which formed a southern projection on the craton, the Ouachita geosyncline in this area was attenuated and the frontal zone of the belt developed in a restricted form. In subcrop, a narrow thrust slice of slightly metamorphosed pre-Tesnus rocks occurs north of the metamorphic rocks of the interior zone and indicates that at least some lower Paleozoic Ouachita facies rocks were deposited. The Devils River uplift appears to have influenced the location and development of the Ouachita geosyncline, and it certainly was a resistant element during deformation of the belt as the foreland facies lower Paleozoic rocks which mantle the Precambrian rocks are deformed and very weakly metamorphosed. This is the only area known where foreland facies rocks are metamorphosed.

Frontal Zone East of the Ouachita Mountains

The nature and extent of the frontal zone of the Ouachita belt east of Arkansas and south of Texas are little known. Drilling in southeastern Mississippi indicates a disturbed zone wherein foreland beds of lower and upper Paleozoic age are juxtaposed with weakly metamorphosed Ouachita slates and phyllites (p. 93). This zone probably marks the front of the Ouachita belt but nothing is known about the interior of the belt south of the front. The presence of weakly metamorphic rocks adjacent to foreland rocks suggests that either (1) frontal zone rocks are metamorphosed here as they are in the Broken Bow–Benton anticlinorium of the Ouachita Mountains salient and the anticlinorium extends southeastward or (2) the frontal zone of Ouachita facies rocks has been overridden by rocks of the interior zone of the belt, as in the Kinney-Val Verde County area of Texas (Pl. 2). The band of deformed and weakly metamorphosed Pennsylvanian rocks which parallels the belt (Pl. 3) may in part lie within the frontal zone.

Frontal Zone in Mexico

Rocks like those in the frontal zone of the Ouachita belt in the United States occur in widely separated areas of northern Mexico (p. 99), but control is not sufficient to map the trend and course of the frontal zone in this region. Scattered outcrops and wells suggest that frontal zone rocks occur in eastern Chihuahua and western Coahuila and that most of the remainder of Coahuila is occupied by metamorphic and igneous rocks of an interior zone.

Differences Between the Salients and the Concealed Texas Segment

The map (Pl. 2) indicates a general contrast between the pattern of the Ouachita belt in the two major salients and in the Texas segment between them. The salients are strongly convex toward the craton, and within them the frontal zone of the belt is very broad. Between, the frontal zone is narrow, and in Kinney, Val Verde, and Terrell counties it is completely missing. Besides their general differences in tectonic pattern, the salients and the concealed recess in Texas differ as follows:

(1) Both salients were affected by marked post-orogenic uplift so that they are now exposed or partly exposed as a result of post-Cretaceous doming.

(2) In both salients beds as young as Atoka occur well within the belt and form synclinoria in the frontal zone, whereas between the salients these younger rocks are preserved only where they were involved in deformation along the frontal margin. Between the salients most of the frontal zone is composed of Stanley, Tesnus, and older rocks of Ouachita facies.

(3) In both salients the frontal zone includes rocks of transitional and foreland facies along their northern margin. In the concealed segment in Texas the facies boundary nearly coincides with the structural boundary, and the zone where foreland facies rocks occur within the structural belt is either much narrower or absent.

Development of the Salients

Differences between the Ouachita Mountains and Marathon salients and the interim segment suggests that the salients were originally wide asymmetric foredeeps that received foreland deposits along their northern and more gently sloping sides and Ouachita detritus from an interior uplift of the belt along their deeper and steeper southern sides. These basins were depressed and received sediments in Jackfork and Atoka time while the frontal zone of the Ouachita belt in north and central Texas was already undergoing uplift. This is well illustrated by the distribution of the Jackfork sandstone in Fannin County, Texas, and the southwestern Ouachita Mountains (Pl. 2). This area was the southwestern end of a great complex northeast-plunging syncline in which the Ouachita Mountains sedimentary rocks were deposited; Jackfork sandstone was preserved along the axis of the syncline in Fannin County.

Deformation of the very thick sedimentary rocks in the salients intensified and concentrated their sedimentary loads. Subsequent epeirogenic uplifts in both the Ouachita Mountains and Marathon salients reflect the buoyancy of this great mass of sedimentary rocks.

INTERIOR ZONE OF THE OUACHITA BELT

General remarks.—The interior zone of the Ouachita belt comes to the surface in only one place, along the west-facing scarp of the Sierra del Carmen south of the Rio Grande near Boquillas, Coahuila, Mexico. Other exposures of metamorphic and igneous rocks in northern Mexico are perhaps part of this interior zone but correlations are uncertain (Flawn and Díaz G., 1959). The discontinuous outcrops in the Sierra del Carmen are interlayered very fine-grained sericite-muscovite-chlorite schist and phyllite, very fine-grained metaquartzite, and calcite marble. These are highly deformed and sheared and include quartz veins that are cut by later post-deformation quartz veins. Local rapid changes in dip and small folds and faults indicate a highly folded and faulted sequence.

Sporadic cores from the interior zone between the Sierra del Carmen and north-central Texas show effects of a similar strong deformation and likewise contain two ages of veins. All of the field, megascopic, and microscopic observations indicate that the rocks of the interior zone are extensively folded, faulted, veined, and sheared and have been subjected to weak to low-grade regional metamorphism with a strong shearing component.

EXTENT AND NATURE OF THE INTERIOR ZONE

The interior zone of the Ouachita belt has been mapped from Navarro County in north-central Texas southward into Caldwell and Gualalupe counties, thence westward to Brewster County, and thence southwestward into Mexico. The actual extent of the zone is unknown, as well control is restricted to a relatively narrow belt adjacent to the frontal zone; however, present knowledge indicates that the interior zone is an elongate belt more or less parallel to the general course of the Ouachita structural belt. Continuity of the zone is lost in Uvalde County, but wells in Zavala and Maverick counties (Pl. 2) suggest that it is present south of Uvalde County. Farther west, in Kinney, Val Verde, Terrell, and Brewster counties, the interior zone is again mappable.

Two lithologic units occur in the interior zone. Most of it is fine-grained schist-phyllite-slate-metaquartzite-marble (p. 79), but from Travis County westward to Bexar County there is a narrow east-west-trending belt of black graphitic slate along the northern border (p. 78). This slate was intensely sheared and microstructures reveal that the rock deformed almost plastically. Cores from widely separated wells (Woodward No. 1 Schubert, Hays County; Stanolind Oil and Gas Company No. 1 Schmidt, Guadalupe County; General Crude Oil Company No. 1 Rogers Ranch, Bexar County; Pl. 2) are nearly identical. In Bexar County and farther west in Medina and Maverick counties, sheared and altered volcanic rocks appear to occur within the interior zone.

BOUNDARY BETWEEN THE INTERIOR AND FRONTAL ZONES

The boundary between the frontal and interior zones of the Ouachita belt is shown on the map (Pl. 2) as a continuous line called the Luling front, but this is a simplification. In some areas, the boundary appears to be relatively sharp, with a change in short distance from unmetamorphosed Mississippian-Pennsylvanian rocks of the frontal zone to highly sheared low-grade metamorphic rocks of the interior zone. In these areas the interior zone seems to be allochthonous and bounded by a zone of overthrusting. Elsewhere, the boundary appears to be more transitional, particularly in south-central Texas where it cuts across the dark clastic lithologic unit so that very weakly metamorphosed rocks in the frontal zone are adjacent to highly sheared weakly metamorphosed rocks in the interior zone, and the over-all lithology is similar on both sides. However, even in this area the two zones can be distinguished by the strong shearing which occurred in the interior zone. The extraordinary high shearing in the black slate adjacent to the Luling overthrust front suggests that this was an incompetent unit along which the interior zone was displaced. Partly mylonitized igneous rocks occur along the same trend farther west.

The interior zone of the Ouachita belt is thus distinguished by its deformational features rather than by any particular lithology. By analogy with the Blue Ridge tectonic province of the Appalachians, deformation in the interior zone of the Ouachita belt east and south of the Luling overthrust front probably involved basement rocks, while deformation in the frontal zone was superficial.

GRAVITY ANOMALIES OF THE OUACHITA BELT

The structural grain of the Ouachita belt is well expressed on regional gravity anomaly maps of the southern United States as a series of maxima and minima strongly elongated parallel to the strike of the belt. These are better defined in Texas than in the area of the Mississippi embayment to the east where the reflection of the Ouachita belt is subdued by a thick cover of younger rocks. Gravity features of the area east of the Mississippi River are discussed in some detail by P. B. King in another section of this report (p. 94 and fig. 4).

The foreland side of the Ouachita belt is marked by a band of pronounced gravity minima which more or less seems to correspond with the frontal zone of the belt and suggests that the prism of folded and faulted sedimentary rocks is very thick. Southeast of the line of strong minima are a series of disconnected maxima overlying the interior zone of the belt. It seems likely that those anomalies are caused by changes in lithology within the interior zone, perhaps by a series of intrusions, but no data are available on the nature of the rocks underlying the anomalies.

Geophysics of the Ouachita Mountains have been discussed by Howell and Lyons (1959); they report a "truly great negative anomaly" over the area of the mountains (which lie entirely within the frontal zone of the Ouachita belt). The conclusions of Howell and Lyons (1959, pp. 57–58), based on gravity data and limited magnetic data, are summed up as follows: (1) The Ouachita Mountains are a very thick prism of sedimentary rocks; (2) the basement is deep and irregular with local uplifts; (3) folding and faulting were accompanied in some areas by intrusion of magnetite-bearing igneous rock.

Southeast of the great minima of the Ouachita Mountains, the course of the Ouachita belt across the Mississippi embayment is suggested by a number of rather weak and vague northwest-southeast elongated anomalies in Mississippi and Alabama; these appear to intersect the southwest-trending Appalachian gravity pattern at nearly right angles in southwest Alabama (fig. 4), but relations are not clearly shown.

In summary, regional gravity data indicate that: (1) The frontal zone of the Ouachita belt is a thick sedimentary mass, and (2) the interior zone is made up of masses of rock of different densities.

PROBLEM AREAS

Some parts of the Ouachita structural belt present vexing problems in tectonic interpretation, especially the area of the Ouachita-Arbuckle junction in southeast Oklahoma and northern Texas and the area of Uvalde and Kinney counties, Texas, where there is a major structural discontinuity or divergence in the belt.

OUACHITA-ARBUCKLE JUNCTION

In southeastern Oklahoma the outcropping rocks and structures of the Ouachita Mountains are overlapped by Cretaceous rocks along a line which extends approximately east-west through McCurtain, Pushmataha, Atoka, and Johnston counties; south of this line the Ouachita belt is concealed. The Cretaceous blanket obscures the junction of the Ouachita belt and the Arbuckle element, and it is in this zone of extreme structural complexity that the continuity of the Ouachita belt is lost. Thus, with one exception, none of the major structures that have been mapped in the Ouachita Mountains can be projected with confidence into the subsurface in Texas. The exception is the axis of the Broken Bow–Benton anticlinorium which can with fair certainty be extended southwestward into Red River and Lamar counties, Texas. Along the northwestern front of the Ouachita belt in Atoka County a series of major thrust faults (Jackfork Mountain, Windingstair, Ti Valley, Pine Mountain, and Choctaw faults) strike southwestward beneath the Cretaceous overlap. The rocks involved include the Stanley, Jackfork, Johns Valley, and Atoka formations as well as a thin slice of pre-Stanley rocks; where last seen these faults are converging, so that as projected, they intersect the southeast-plunging Arbuckle structures at nearly right angles within a distance of 10 miles (Pl. 2).

Well spacing in southwest Atoka, Bryan, and Marshall counties, Oklahoma, is sufficiently dense to map the southeastern extent of the Arbuckle element. Arbuckle facies rocks have been encountered in the subcrop in southeastern Bryan County close to the Red River about 30 miles from the edge of the overlapping Cretaceous rocks (Pl. 2) so that there is a very abrupt structural recess in the front of the Ouachita belt in this area. The telescoped thrust-faulted sequence of Ouachita rocks on the northeast side of the Arbuckle element suggests large-scale tear faulting, wherein the deformed Ouachita rocks were moved northwestward relative to the Arbuckle rocks (Flawn, 1959b). The discontinuity in the Ouachita belt is thus not merely a discontinuity due to the concealing cover but a major structural discontinuity caused by an unyielding Arbuckle buttress. On the southwest side of the Arbuckle element the situation appears to be much the same. In Grayson County, Texas, the Ouachita front is marked by an overthrust that has been penetrated in a number of wells (minimum displacement, 6 miles); moreover, well density is adequate to map broadly the subcrop contact between pre-Stanley rocks and the Stanley shale (Pl. 2 and fig. 13). In Grayson County and in southern Marshall County, Oklahoma, dislocated Ouachita rocks occur many miles northwest of the Arbuckle facies rocks which form the subcrop in Bryan County, Oklahoma. The pattern is one which suggests tear faulting with the southwest side moving northwest.

The frontal overthrust of the Ouachita belt southwest of the Arbuckle element in Grayson County is not necessarily correlative with the Choctaw frontal fault on the northeast side of the Arbuckle element. Because of the intervening foreland mass no correlation can be made, and the Grayson County fault may be equivalent to one of the interior thrusts of the Ouachita Mountains.

In the northeastern and northern Ouachita Mountains, the thrust during the

Ouachita orogeny was absorbed by the tremendous mass of sediments in the Arkansas basin without any major dislocation. Farther west the Ouachita rocks were thrust against the unyielding Arbuckle buttress which caused both extensive overthrusting and large-scale transverse faulting with a probable minimum displacement of 30 miles. Most of the northwestern movement of the Ouachita Mountain mass was probably effected by thrust faulting and tear faulting along the northeast side of the Arbuckle element (fig. 13), as suggested earlier by Miser (1929, pp. 12–25; 1959, pp. 32–33), Hendricks et al. (1947), and Hendricks (1959, pp. 48–50).

Position of the Ouachita Front in Grayson and Collin Counties, Texas

Figure 13 shows two interpretations of the position of the Ouachita front in Grayson and Collin counties Texas, based on different interpretations of the stratigraphic sequence penetrated in Rutledge No. 1 Williams (p. 263), Verne Dumas Company et al. No. 1 Williams (p. 259), and Deep Rock Oil Corporation No. 1 Sherley (p. 241). The answer to the problem hinges on interpretation of well samples—whether the Ouachita facies Bigfork chert fragments in the Williams wells are derived from tectonically transported Ouachita rocks or from pebbles and cobbles in Pennsylvanian conglomerates, and whether the lower sequence in the No. 1 Sherley is Ouachita facies Womble or foreland facies Pennsylvanian. Although in the regional view the problem is not of great importance, production of oil and gas from foreland rocks immediately adjacent to the Ouachita front in this area makes an accurate delineation of the front a problem of economic significance. Coring of the pre-Cretaceous section in this area would contribute a great deal of valuable information on the nature, attitude, and intensity of jointing and fracturing in these rocks.

Uvalde and Kinney Counties, Texas

In Bexar and Medina counties, Texas, the Ouachita belt, with a well-developed frontal zone and a well-marked boundary between the frontal zone and interior zone, strikes westward into a problem area in Uvalde and Kinney counties. Farther west, in Val Verde County, the Ouachita belt trends northwest toward the Marathon salient, and the frontal zone is either missing or is extremely narrow. The geology of the problem area is as follows:

(1) A buried Precambrian buttress, the Devils River uplift, lies in southern Kinney and Val Verde counties; it is mantled by lower Paleozoic foreland rocks and is overridden or partly overridden by rocks of the interior zone of the Ouachita belt.

(2) Frontal zone Ouachita rocks occur in northern Uvalde County, north of foreland rocks in Kinney County—this indicates that the Ouachita front in western Uvalde County turns southwest, almost at right angles to the trend of the belt in Kinney and Val Verde counties (Pl. 2).

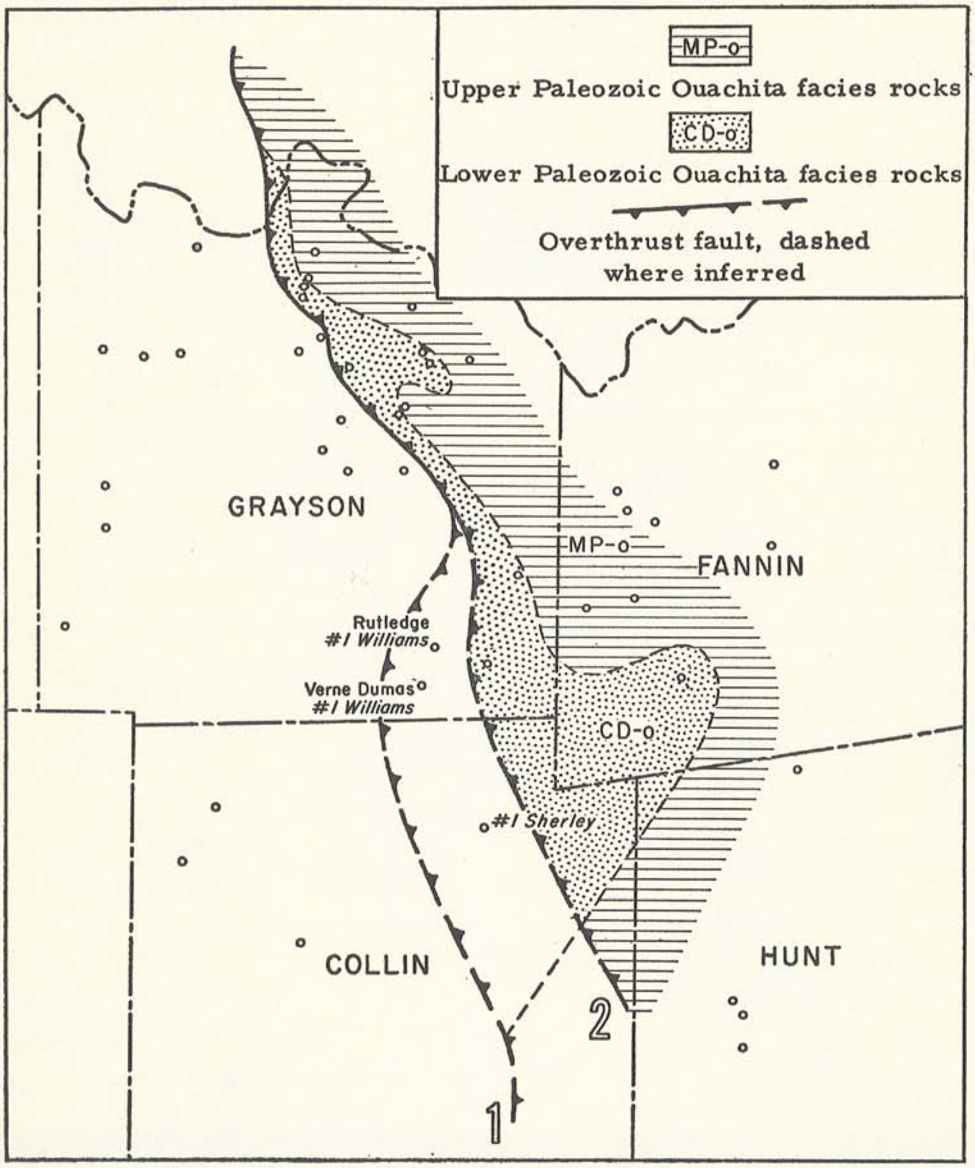
(3) This area of sharp change in trend of the Ouachita belt is also an area of profuse intrusion of Cretaceous-Tertiary igneous rocks.

Association of a discontinuity in the Ouachita belt and an area of high-standing Precambrian rocks is probably more than a coincidence, and the writer (Flawn, 1959c) suggested that:

(a) At the beginning of Paleozoic time the area of the Devils River uplift in southern Kinney and Val Verde counties formed a stable lobe on the southern edge of the craton, much like the Llano uplift farther to the east. The Cambro-Ordovician sequence on the Devils River uplift (p. 144) and on the Llano uplift is similar so that the two areas must have had a similar early Paleozoic history.

(b) The Ouachita geosyncline, with perhaps a somewhat restricted frontal trough, formed south of this uplift, whereas farther west and east the foreland side of the geosyncline was more broadly developed (figs. 2, 3).

(c) Deformation of the geosyncline was affected by the Devils River uplift; south of it the frontal zone was crushed against the buttress and the interior zone overrode both the frontal zone and the south flank of the buttress. Farther west, the Marathon salient advanced over the foreland and to the east another salient formed in Uvalde County. Perhaps tear faulting occurred along the east and west sides of the Devils River buttress, and possibly deep-seated shears on the east side provided zones of weakness along which the younger intrusive rocks were emplaced. The tear faults shown on Plate 2 are schematic and based on pattern of outcrop and theoretical considerations. There is no direct evidence for their existence.



POSITION 1. Rutledge No. 1 Williams and No. 1 Sherley interpreted as having penetrated an overthrust fault separating dislocated Ouachita rocks (Ordovician) above from foreland rocks (Pennsylvanian) below; Verne Dumas No. 1 Williams interpreted as having penetrated Ouachita rocks of the overthrust plate (*see* Pl 2).

POSITION 2. Rutledge No. 1 Williams, Verne Dumas No. 1 Williams, and No. 1 Sherley interpreted as having penetrated Pennsylvanian conglomerate containing fragments of Ouachita rocks.

FIG. 13. Position of the Ouachita front in Grayson and Collin counties, Texas.

History of the Ouachita System[33]

PHILIP B. KING

Preceding parts of this publication set forth the facts available regarding the Ouachita system of Texas and adjacent states and the inferences that can reasonably be derived therefrom. This summary is more speculative and is colored by the predilections of its author, not only regarding the origin and development of the Ouachita system but of orogenic systems in general.

PRECAMBRIAN FRAMEWORK

Much is known of the history of Precambrian time in the Canadian Shield in the heart of the continent, and in recent decades this history has been strengthened by many radiometric determinations of "absolute" ages. Nevertheless, many uncertainties remain (James, 1960, pp. 108–113). These uncertainties are compounded in surrounding parts of the Central Stable Region and in the orogenic belts beyond, where Precambrian rocks emerge from the cover of younger rocks in few places, and only scattered information is available from drilling in intervening areas. Flawn (1956, pp. 23–52), Thiel (1956, pp. 1085–1093), and Burwash (1957, pp. 96–101) have interpreted the Precambrian of parts of the region outside the Canadian Shield, similar investigations are in progress elsewhere, and Gastil (1960, pp. 9–10) has made a more generalized interpretation of the whole region.

The margins of the continent in Precambrian time are even less known. Precambrian rocks are exposed across part of the Appalachian and Cordilleran systems on the east and west, but not near their oceanward edges, and none reach the surface in the Ouachita system on the south, where the lowest exposed strata are probably considerably above the base of the Paleozoic column.

A basement of sialic metamorphic and plutonic rocks which has yielded radiometric ages of a billion years or more emerges in the Appalachians as far east as the Blue Ridge, and in the Cordillera somewhat farther west than the Grand Canyon representing margins of the continental plate that were downwarped beneath the miogeosynclines of later time. Precambrian basement rocks are exposed in few places nearer the oceans, in the eugeosynclinal areas of later time (Gilluly, 1955, p. 12), and the Precambrian age of some of the reported occurrences is questionable (as in the Klamath Mountains of northern California). The floor on which the later eugeosynclinal deposits were laid might have been simatic and oceanic crust, rather than sialic and continental, and the eugeosynclinal areas may only have been added to the continent by later accretions and consolidations (Wells, 1949, p. 1927).

Regardless of the nature of their basement, geosynclines originated along the eastern and western sides of the continent before the beginning of Paleozoic time.

Earliest Cambrian strata in the Blue Ridge province of the central and southern Appalachians are separated from basement plutonic and metamorphic rocks by thick stratified sequences which must be of late Precambrian age, as in many places there is no clear discordance between them and the earliest Cambrian. In Virginia these strata include the Catoctin greenstone and related volcanic rocks and the metasedimentary Lynchburg gneiss; in Tennessee, North Carolina, and Georgia they include the even thicker mass of graywackes and other clastic rocks of the Ocoee series. All these strata have some of the

[33] Publication authorized by Director, U. S. Geological Survey.

features of eugeosynclinal deposits of later time, although the analogy is not complete.

Precambrian geosynclinal deposits in the Cordilleran region are best exemplified by the Belt series (Purcell series of Canada) in the northern Rocky Mountains whose eastern phases, with units of limestone, red argillite, and other shallow-water deposits, are typically miogeosynclinal but which pass farther west into more dominantly clastic eugeosynclinal rocks. The Belt is known to overlie older basement rocks toward the east but its base is not visible farther west. Surprisingly ancient dates of more than a billion years have been determined from veins in the Belt series (Eckelmann and Kulp, 1957, p. 1130), suggesting that geosynclinal conditions along this segment of the continent began during or before the final consolidation of the Canadian Shield itself. The ancient age of the Belt is further attested by its unconformable relations with the succeeding and equally thick Windermere series of Canada, which is apparently of latest Precambrian age as it is conformable with the succeeding geosynclinal deposits of Paleozoic time.

Precambrian geosynclinal deposits are more fragmentarily preserved farther south in the Cordillera but include the quartzites and slates of the Uinta Mountain group and related units in Utah, the Grand Canyon series of northern Arizona, and the Pahrump series and Apache group to the west and south. The Grand Canyon, Pahrump, and Apache include units of limestone, sandstone, shale, and minor lava and seem to be typically miogeosynclinal. Their ages are undetermined, but all of them are at least younger than basement rocks, which in the Grand Canyon have yielded a radiometric date of about 1.3 billion years (Aldrich, Wetherill, and Davis, 1957, p. 656).

Precambrian history along the southern margin of the continent, adjoining the Ouachita system, is less understood than along the east and west margins. Information, still partly unpublished, indicates that during later Precambrian time rhyolitic lava covered an extensive part of the Central Stable Region in Oklahoma, Texas, and New Mexico. Lopolithic intrusions of gabbro and granophyre in the Wichita Mountains of Oklahoma have yielded the very late Precambrian date of about 0.6 billion years (Hamilton, 1956, p. 1325). In west Texas, perhaps also late in Precambrian time, strata resembling the Grand Canyon series and its allies were strongly deformed and were welded to the continent as the Van Horn orogenic belt (P. B. King and Flawn, 1953, pp. 131–132; Flawn, 1956, pp. 32–35). Some resistant massifs of earlier basement rocks can be identified along the southern margin of the Central Stable Region, including the Llano uplift in Texas and the Arbuckle Mountains in Oklahoma, whose rocks have yielded radiometric ages in excess of a billion years (Flawn, 1956, p. 27; Hamilton, 1956, p. 1328). Some other massifs, including the Devils River uplift southwest of the Llano uplift, are now wholly buried but may be of similar nature.

Precambrian rocks are unknown within the Ouachita system itself. However, if the Ouachita system is similar to the Appalachian and Cordilleran systems it is likely that a wide part of it on the side toward the continent is underlain by sialic basement rocks, downflexed before the beginning of Paleozoic time to permit at least local accumulations of younger Precambrian geosynclinal deposits. This initial downflexing would have influenced the course of the Ouachita geosyncline during Paleozoic time and, in turn, the pattern of the Ouachita orogenic system. Present sinuosities of the Ouachita system were clearly accentuated by thrusting of the Paleozoic geosynclinal rocks into the salients during the orogenic phase, but one of the recesses is opposite the massif of the Llano uplift. This massif resisted the thrusting of later Paleozoic time, and it may also have deflected the zone in which the basement was downflexed during later Precambrian and earlier Paleozoic time.

EARLY GEOSYNCLINAL PHASE (CAMBRIAN TO DEVONIAN)

The Appalachian and Cordilleran systems were well differentiated from the Central Stable Region by the beginning of Paleozoic time. The farthest inland extent of the Lower and Middle Cambrian series on the east and west is near the edges of the geosynclines as they existed through most of the later part of the era (Kay, 1951b, pp. 7–11; P. B. King, 1959, pp. 25–26), and only the Upper Cambrian series overlaps widely over the Central Stable Region.

A comparable differentiation has not been established south of the Central Stable Region. The basal Paleozoic deposit in the Arbuckle and Wichita Mountains of southwestern Oklahoma is the Reagan sandstone, whose Late Cambrian age indicates that the geosyncline of the Wichita system originated much later than those of the Appalachian and Cordilleran systems. In the Ouachita system the oldest fossiliferous rocks are of comparable age or younger. In the Marathon region these include the Dagger Flat sandstone and Marathon limestone, with fossils of Late Cambrian, early Early Ordovician (Tremadocian), and Early Ordovician age (J. L. Wilson, 1954b, p. 254; Berry, 1960, p. 5). In the Ouachita Mountains the oldest fossiliferous beds, in the Mazarn shale, contain graptolites no older than those in the upper part of the Marathon limestone (zone 4, above Monument Spring member; Berry, 1960, p. 35). The Mazarn is underlain by the unfossiliferous Crystal Mountain sandstone, Collier shale, and Lukfata sandstone of W. D. Pitt (1955), parts of which have been assigned to the Cambrian, but none of which may be older than the earliest Ordovician (Ham, 1959, pp. 81–82).

Nevertheless, geosynclinal conditions probably began much earlier in Paleozoic time in the Ouachita system than in the Wichita system. No basement rocks like those in the Wichita system emerge in any Ouachita area, and the oldest Paleozoic rocks exposed there are probably not near the base of the stratified sequence. The characteristic folds and fault slices in the Ouachita Mountains and Marathon region could have formed only over a thick mass of incompetent strata (King, 1937, p. 22), and the existence of such strata is attested by one 14,000-foot hole in the Marathon region (Turner No. 1 Coombs, in the Dagger Flat anticlinorium), which penetrated only sandstones and shales to the bottom. Even though these rocks are highly deformed, they could scarcely have been derived from a sequence that was originally thin. These inferences are confirmed by gravity data. All the uplifts in the Wichita system, where basement rocks are known to be at or near the surface, show positive anomalies, whereas none of the anticlinoria in the Ouachita Mountains produce any variation in the prevailing large negative anomaly of that region (Howell and Lyons, 1959, p. 57). A similar, but smaller, negative anomaly occurs in the Marathon region, where the older rocks of the Ouachita system are again exposed. The age of the inferred mass of strata beneath the exposed rocks of the Ouachita system is unknown, except that it is older than latest Cambrian.

During Paleozoic time miogeosynclinal belts were extensive east and west of the continent, in the Appalachian and Cordilleran systems. The lower halves of the deposits laid down in the miogeosynclinal belts are dominantly units of carbonate rocks with subordinate shale and sandstone, formed in water of moderate to shallow depth. They resemble the deposits laid down in the continental interior but are much thicker, due to greater subsidence in the miogeosynclinal belts.

Eugeosynclinal belts were farther away from the continent to the east and west —certainly in the northern Appalachians, less certainly in the southern Appalachians, and nearly continuously along the oceanward side of the Cordillera. Miogeosynclines and eugeosynclines were either parts of single troughs or were separated by barriers, but rocks of the two sequences are now mostly juxtaposed along structural discontinuities. Various absolute criteria have been used for identification of eugeosynclinal sequences—presence of volcanic rocks and chert; sandstone of the graywacke suite rather than of the quartzite suite; subordination of carbonate deposits; a distinctive biofacies such as that dominated by graptolites in early Paleozoic time; greater thicknesses of deposits than in the miogeosynclinal or interior sequences; and sedimentation in waters of greater depth. But the combinations of these criteria vary from one eugeosynclinal sequence to another, or even from one part to another of a single sequence, and in many sequences one or more of the criteria are inapplicable. Nevertheless sedimentation in all eugeosynclinal sequences was controlled to a greater extent by tectonic forces than in depositional realms nearer the continental interior.

Classification of the early Paleozoic deposits south of the continent is more perplexing than that of the deposits to the east and west. The early Paleozoic sequence in the Wichita system of southwestern Oklahoma much resembles the miogeosynclinal sequence of the southern Appalachians, but it lacks the thick Lower and Middle Cambrian elements of that area. Within the Ouachita system a miogeosynclinal belt is indicated only in places. Carbonate rocks like those of the miogeosynclinal belt of the southern Appalachians extend in subcrop into east-central Mississippi, where they seemingly wedge out against the main belt of the Ouachita system (pp. 89–90). In the part of the Ouachita Mountains of Oklahoma north of the Ti Valley fault the Devonian Pinetop chert and underlying limestone approach a miogeosynclinal aspect; rocks beneath them are not exposed and their character is undetermined (Hendricks et al., 1947). Ordovician rocks of the Ouachita system in the Marathon region contain fossiliferous boulders derived from Upper Cambrian and Lower Ordovician carbonate rocks that are in part older than any known nearby in the interior region (J. L. Wilson, 1954b, pp. 254–258), which may have been derived from a narrow intervening miogeosynclinal belt. Nevertheless, it seems unlikely that a miogeosynclinal belt could ever have been extensive along the front of the Ouachita system or could have been much concealed by later thrusting.

This situation is not unique, as widths of miogeosynclinal belts vary in other orogenic systems because of local tectonic peculiarities. The miogeosynclinal belt in the segment of the Cordilleran system in the Great Basin is nearly 300 miles broad yet is less than 100 miles broad in the segment in Alberta and British Columbia. The miogeosynclinal belt is as much as 100 miles broad in the central and southern Appalachians, yet in a 500-mile segment farther north, between Vermont and Gaspé, it is lacking on the outcrop so that Cambrian and Ordovician eugeosynclinal rocks abut the foreland on the northwest (Cady, 1960, p. 558). These rocks, like those in the Ouachita system, contain fossiliferous boulders of miogeosynclinal carbonate rocks, but it is doubtful whether these rocks were ever extensive. Local tectonic peculiarities that could inhibit the development of a miogeosynclinal belt are speculative; they might include a more abrupt downflexing of the continental margin than elsewhere, or a lack of barrier ridges between the eugeosyncline and the continent so that eugeosynclinal sediments could spreal freely over the whole geosynclinal tract.

Although the early and middle Paleozoic deposits of the Ouachita system form a distinctive suite, their features do not correspond exactly to any of the usual classes of geosynclinal deposits, and even their geosynclinal origin has been questioned

(J. M. Barton, 1945, p. 1346; Harlton, 1953, p. 796; Ham, 1959, p. 85).

Early and middle Paleozoic deposits of the Ouachita system exposed in the Ouachita Mountains and Marathon region include distinctive units of chert and other siliceous deposits (the Middle Ordovician Fort Peña formation, the younger Ordovician Bigfork and Maravillas cherts, and the Devonian and Mississippian Arkansas and Caballos novaculites).[34] Units of shale and slate are associated with the siliceous strata, which in the Ouachita Mountains include interbedded layers and a few thicker units of sandstone, but in the Marathon region they are more calcareous and include much flaggy argillaceous limestone.

Few linkages exist between the Ouachita sequence and its fossils and the carbonate rocks and their fossils in the Wichita system and other parts of the interior region. The earliest link is by means of the Monument Spring dolomite member of the Lower Ordovician Marathon limestone in the Marathon region, which marks a momentary incursion of the carbonate facies and its fossils into a prevailing graptolite-bearing facies. The cherts and limestones of the later Ordovician Maravillas and Bigfork formations are part of a blanket of deposits that also spread widely into the interior region, where it includes the Montoya and Viola limestones. All these formations have been classified from time to time and from one part to another as of Trentonian, early Cincinnatian, and late Cincinnatian age, and no doubt they vary somewhat in scope from place to place by addition or subtraction of beds at the base and top, but their general continuity is beyond question. The Devonian and Mississippian Caballos and Arkansas novaculites link with the Woodford chert.

Thicknesses of exposed sequences of the early and middle Paleozoic rocks in the Ouachita system are not impressive, compared with sequences of equivalent age in the Wichita system and the West Texas basin (J. M. Barton, 1945, p. 1338; Ham, 1959, p. 84). In the Ouachita Mountains the exposed pre-Silurian strata are about 5,000 feet thick and the Silurian and Devonian 2,700 feet, compared with thicknesses of 11,000 and 900 feet, respectively, for equivalent strata in the Arbuckle Mountains. In the Marathon region the thickness of the Caballos novaculite and exposed older strata is about 2,900 feet, whereas the thickness of equivalent strata in the West Texas basin is nearly twice as great.

The dominant fact of sedimentation in the Ouachita system during much of early and middle Paleozoic time was a stagnant sea, inhibiting the growth of a bottom fauna, so that most of the preserved fossils are pelagic forms such as graptolites. The novaculite formations, deposited later than the time of the graptolites, contain sapropelic spore-bearing layers, which also indicate at least intermittent stagnant conditions (Goldstein and Hendricks, 1953, p. 440). Nevertheless, sedimentary structures throughout the Ordovician sequence in the Marathon region show that it accumulated in prevailingly shallow water (King, 1937, p. 45; Berry, 1960, pp. 32–34). Less is known regarding depth of water during accumulation of the sediments of the Ordovician and Silurian sequence in the Ouachita Mountains area, although indications of shallow-water origin are reported in some layers (Miser and Purdue, 1929, pp. 127–131).

Unconformities have been reported at various levels in the sequences of both the Ouachita Mountains and Marathon region, but their origin and the amount of hiatus represented by each is uncertain. In the Marathon region the Maravillas chert and Caballos novaculite are separated by a dis-

[34] The writer does not accept the radical restriction of the Caballos novaculite proposed by Berry and Nielsen (1958) but believes that the term should be applied, as it has been for more than 40 years, to the whole body of novaculites and cherts that intervene between the Maravillas and Tesnus formations. Used in this sense, the Caballos is nearly or wholly identical, even in subdivisions, with the Arkansas novaculite of the Ouachita Mountains. In both areas these subdivisions, probably with a wide range of Devonian and Early Mississippian ages, will no doubt eventually be defined as named formations, at which time both Caballos and Arkansas novaculites should be redefined as groups.

conformity whose hiatus represents all of Silurian time or longer, yet it is questionable whether there was much uplift, emergence, or erosion of the underlying beds. Moreover, some of the units were formed during long spans of time—the Maravillas chert during part of Middle Ordovician and all of Late Ordovician time (Berry, 1960, p. 33), the Arkansas and Caballos novaculites during much of Devonian and part of Early Mississippian time—suggesting prolonged stability and slow accretion of sediments. Unconformities are indicated by physical evidence at various levels in the Ordovician of the Marathon region, but Berry (1960, pp. 5–8) believed that the sequence of graptolite zones is complete; the supposed breaks may thus represent little or no hiatus. Less can be determined regarding the magnitude of unconformities observed between the various Ordovician and Silurian units in the Ouachita Mountains, because detailed zonation is prevented by wide spacing of fossiliferous horizons and localities.

Early and middle Paleozoic deposits of the Ouachita system are more shaly, sandy, and siliceous than deposits of corresponding ages in the interior region. The sandstones in different parts of the Ouachita Mountains sequence are variously classifiable as orthoquartzites, protoquartzites, subgraywackes, and lithic graywackes (Goldstein, 1959a, p. 107), and those in the Marathon sequence of the Cambrian and Ordovician are mostly classed as subgraywackes (Berry, 1960, pp. 32–34). Each of these varieties implies differences in the nature, and perhaps in the position, of the source area. Some of the orthoquartzites, like those in units near the base of the Ouachita Mountains sequence, might have been derived from low lands in the interior region. Other sandstones, most of which are less well-sorted subgraywackes or graywackes, were derived from within the Ouachita system, as shown by increasing sandiness of limy or shaly formations southeastward across the area of exposure, and the wedging in of sandstone units in the same direction. These sandstones might have been derived from intermittent pulses of uplift in varied tectonic lands within the geosynclinal area. Although the ultimate sources of all the sands were crystalline rocks, at least some of them were resedimented from earlier deposits. Source areas need not have been directly opposite the sites of deposition, as longitudinal filling of sedimentary basins was a more common event than has been generally supposed (Kuenen, 1957). All the directional structures observed by Berry (1960, pp. 32–33) in the Marathon Ordovician sequence indicate transport of sediments to the northeast, probably along rather than across the trend of the depositional basin.

Some of the pulses of uplift recorded by the sandstone wedges may reflect early times of orogeny within the Ouachita system, akin to the Taconian or Acadian orogenies of the inner parts of the Appalachian system. A minor pulse is suggested by the Blakely sandstone in the Ouachita Mountains and the Rodriguez Tank sandstone of Berry (1960, p. 20) in west Texas, both of early Middle Ordovician age, and a greater pulse is suggested by the thicker Blaylock sandstone of the Ouachita Mountains, of Early Silurian age. The polymetamorphic fabrics observed by Flawn in many well cores from the interior zones of the Ouachita system in central Texas ("Metamorphism," pp. 121–124) suggest that one or more orogenies occurred before the climactic late Paleozoic orogeny, some of which may have been as early as Silurian or Ordovician time. However, the boulder beds in the Middle and Upper Ordovician formations in the Marathon region are not orogenic products but resulted merely from faulting along the northwest margin of the depositional area during times of unusual subsidence (J. L. Wilson, 1954b, p. 258).

Bedded cherts and other siliceous rocks are among the most perplexing of sediments. Even the classic radiolarian cherts of the Franciscan formation in California, whose spatial relations to spilitic lava are obvious and whose genetic relation is likely, contain little internal indications of source. Silica-secreting organisms such as radiolarians and sponges clearly are no more than incidental constituents, although their remains are common in the chert. The cherts and siliceous rocks of early and middle Paleozoic age in the Ouachita system share the perplexities of their class and have been diversely interpreted. The most convincing hypothesis is that of Goldstein and Hendricks (1953, pp. 440–441), that they were derived ultimately from falls of siliceous volcanic ash, which were altered diagenetically on the sea floor during long exposure and slow burial. The Upper Ordovician chert formations and the Devonian and Mississippian novaculite formations are thought to have formed during times of greatest volcanism and ash falls, when there was little influx of clastic sediments into the area of deposition.

We can now revert to the classification of the environment of the early and middle Paleozoic deposits of the Ouachita geosyncline, a problem unlikely to be resolved by application of a few absolute criteria. There is a tantalizing resemblance between them and the "leptogeosynclinal" deposits of parts of the Alpine geosyncline (Trümpy, 1960, pp. 865–869), as both are relatively thin sequences representing a long time span and include significant volumes of siliceous sediment. However, available evidence suggests that most of the deposits of the Ouachita geosyncline were laid down in shallow water, whereas those in the Alps are believed to have been laid down in deep water. Nevertheless, the deposits of the Ouachita geosyncline were probably not merely a thinned shoreline facies of the dominant carbonate deposits of the interior region overlapping toward a theoretical land "Llanoria," although this has been inferred (Miser, 1921, pp. 87–89; P. B. King, 1937, p. 44; and later authors). Shoreline deposits would hardly create such remarkably persistent rock and faunal facies for long distances along the system, and differences between the exposed sequences in the Ouachita Mountains and Marathon region would have been greater.

The exposed lower and middle Paleozoic rocks are probably only a part of the deposits laid down at that time in the Ouachita geosyncline, as Flawn's study of drill data indicates that they are marginal to a much broader orogenic belt. It is reported that where lower and middle Paleozoic formations can be identified in drill holes southeast of the outcrops, they are much thicker (Goldstein, 1959a, p. 108); rocks in some of the buried southeastern belts described by Flawn may include units of early and middle Paleozoic age but of unrecognizable facies. Moderate tectonic and volcanic influences on sedimentation are indicated by the sandstone, chert, and novaculite units, whose sediments were probably derived from tectonic lands and volcanic areas within or flanking the Ouachita geosyncline.

The exposed early and middle Paleozoic rocks of the Ouachita system are marginal to the inner zones of the system, like the miogeosynclinal rocks of equivalent age in the southern part of the Appalachian system. They are unlike the usual miogeosynclinal sediments but were deposited in a similar manner—mainly in shallow water on a slowly subsiding foundation. The sediments themselves are more like those of the eugeosynclinal realm than any other. In the Ouachita system extensive development of the usual carbonate rocks of the miogeosynclinal realm was somehow inhibited, and deposits of eugeosynclinal type might thus have been able to spread from the inner zones across the marginal zone, into an area whose structural behavior, at least, was miogeosynclinal.

LATE GEOSYNCLINAL PHASE (MISSISSIPPIAN AND EARLY PENNSYLVANIAN)

The upper part of the sequence in the miogeosynclinal belts of the Appalachian and Cordilleran systems differs fundamentally from the lower in both nature and origin (P. B. King, 1959, p. 59). The lower part is dominantly carbonate rocks, and the few interbedded clastic layers were derived mainly from the continental interior. The upper part is dominantly clastic rocks, which thicken and coarsen toward the inner zones of each system, where the eugeosynclinal belts were in process of deformation. The clastic rocks overspread the miogeosyncline in a succession of wedges, the edges of some of which extend well into the interior region.

These clastic sequences vary from place to place, depending on the local tectonic history. In some segments of the Appalachian system clastic wedges appear in the Middle or Upper Ordovician, in others in the Silurian, Devonian, or even higher; in some segments of the Cordilleran system they first appear near the top of the Paleozoic. In places the difference between lower and upper parts of the miogeosynclinal sequence is absolute, with clastic rocks dominating from the first wedge upward. In others, clastic and carbonate wedges interlock, indicating several widely separated pulses of deformation before the climactic orogeny. A Mississippian clastic wedge thus spreads widely across the central Great Basin from the Antler orogenic belt on the west but interlocks eastward with miogeosynclinal carbonate rocks that were not deformed until Mesozoic time (Roberts et al., 1958, p. 2838).

Many of the earlier clastic deposits are localized within the miogeosynclinal belts and accumulated in deep, linear, rapidly subsiding troughs near the source areas, as did the European flysch (Trümpy, 1960, p. 873). Many of the later clastic deposits are broad wedges or blankets, formed in a complex of continental, estuarine, and shallow-water environments, as did the European molasse (Trümpy, 1960, p. 880). In places successively younger clastic deposits are juxtaposed, each farther inland, indicating progressive consumption by orogeny of the earlier eugeosynclinal and miogeosynclinal tracts.

In the exposed parts of the Ouachita system a fundamental change in sequence like that in the Appalachian and Cordilleran miogeosynclines occurs at the top of the Arkansas and Caballos novaculites. Whereas the sequence from the novaculites downward is dominated by thin, widely spread argillaceous or siliceous units, with a few clastic wedges, the sequence above is a great mass of clastic rocks of Late Mississippian (Meramec and Chester) and of Early Pennsylvanian (Morrow and Atoka) ages. These clastic rocks comprise the Hot Springs sandstone, Stanley shale, Jackfork sandstone, and Atoka formation of the Ouachita Mountains, and the Tesnus and Haymond formations of the Marathon region.

The clastic formations follow the novaculite formations with a hiatus which represents part of Early Mississippian time. In places in the Ouachita Mountains of Arkansas the basal clastic unit is the quartzose Hot Springs sandstone, which probably wedges out by overlap elsewhere. An unconformity is reported at the top of the novaculite formations at many places in both the Ouachita Mountains and Marathon region, with conglomerate at the base of the succeeding deposits, but the break between them may not have been subaerial, and it might represent merely a cessation of sedimentation. Thinning of the inland margin of the clastic deposits was probably more by wedging out of each unit than by overlap.

These clastic deposits have many features in common and are of similar origin, but three principal rock facies occur:

(1) The Stanley shale and Tesnus formation include thin to thick, to very thick units of dark shale, which alternate with thin to thick sandstone layers. The sand-

stone layers are dark, argillaceous, chloritic in part, and are subgraywackes or lithic graywackes which contain much detrital feldspar, mica, and rock fragments. Rocks of this facies are widespread, both in the outcrop areas in the Ouachita Mountains and Marathon region and in the subcrop between the Ouachita Mountains and central Texas, where Flawn observed that they contain abundant detrital biotite, granitic fragments, and high-kaolin shales. The facies resembles the more sandy rocks of Franciscan type in the Mesozoic of California.

(2) The Jackfork sandstone is a thick-bedded, light-colored sandstone, with shale partings. The sandstones are protoquartzites or subgraywackes and are coarser than those of the preceding facies. Their detrital grains are dominantly quartz, although they include appreciable minor constituents. Sandstones of this kind are widespread in the Ouachita Mountains but have been identified only a short distance southward in subcrop into Texas. They are represented in the Marathon region by only a few lenses in the thicker parts of the Tesnus. That part of the Atoka formation which is preserved in the Ouachita Mountains contains many sandstone beds similar to those in the Jackfork.

(3) The Haymond formation of the Marathon region is mostly thinly and rhythmically interbedded sandstone and shale, interrupted by some thick lenses of feldspathic arkose and by boulder beds. This facies is not represented in other parts of the Marathon sequence; it occurs in the Ouachita Mountains in the Johns Valley shale and lower part of the Atoka formation, without the arkose lenses (T. A. Hendricks, written communication, 1960). These thin-bedded sandstones and shales resemble those of the Mesozoic Knoxville and Paskenta formations in California.

Minor constituents of the clastic sequence of the Ouachita system include a thin unit of volcanic tuff in the lower part of the Stanley shale in the interior of the Ouachita Mountains, and eight or nine thin, persistent beds of siliceous shale distributed through the Stanley, the Jackfork, and the lower part of the Atoka. The shales contain conodonts, radiolarians, and other siliceous fossils and are probably of ultimate volcanic origin (Goldstein and Hendricks, 1953, p. 440). Similar beds of siliceous shale occur in the Tesnus formation of the Marathon region.

Minor constituents also include several remarkable boulder beds which contain not only pebbles, cobbles, and boulders but also angular blocks and slabs of diverse earlier Paleozoic sedimentary rocks, some more than a hundred feet across. Boulder beds in the Ouachita Mountains are mainly in the Johns Valley shale of Late Mississippian and Early Pennsylvanian age, but there are a few in the underlying Jackfork sandstone (T. A. Hendricks, written communication, 1960). Those in the Marathon region are somewhat higher in the sequence, in the Haymond formation of Atoka age. In the Ouachita Mountains the boulders and blocks are from formations of the foreland region, such as those now exposed in the Arbuckle Mountains and Ozark uplift, but boulders and blocks in the Marathon region appear to have been derived not only from the foreland region but from uplifts within the geosynclinal area.

The Upper Mississippian and Lower Pennsylvanian clastic rocks are notable not only for their great thickness but for their close restriction to the Ouachita belt itself. The Tesnus formation can be traced on the outcrop across the Marathon region from a near feather edge into exposures on the southeast where it is more than 7,000 feet thick (P. B. King, 1937, pp. 55–56). Abrupt southeastward thickening of the Stanley and Jackfork formations occurs from one thrust slice to the next in the western part of the Ouachita Mountains of Oklahoma (Hendricks et al., 1947), part of which is surely a sedimentary variation, although it has been accentuated by later thrusting. Farther east these units wedge out more gradually, as they have been identified beneath the Arkansas basin north of Little Rock, Arkansas (Maher and

Lantz, 1953) (*see* well 12 in Appendix, Part 3).

Within the Ouachita Mountains the Stanley shale is as much as 12,000 feet thick, the Jackfork sandstone is as much as 7,000 feet, and the Atoka formation preserved above them is as much as 7,000 feet thick; along the mountain front in western Arkansas the Atoka is probably more than 19,000 feet thick (Reinemund and Danilchik, 1957). In the southeastern part of the Marathon region the Tesnus formation is as much as 7,000 feet thick and the Dimple limestone 1,000 feet thick, with incomplete sequences of the overlying Haymond formation more than 3,000 feet thick. The sequence in the Marathon region is impressive but is thinner than that in the Ouachita Mountains, either from a less complete development of the clastic deposits, or because the part exposed is northwest of the depositional maximum.

These clastic deposits of great thickness were derived from tectonic lands within the Ouachita system, which might have been uplifted wedges of basement rocks, deformed geosynclinal rocks, or both. They were not the product of an accidental juxtaposition of unrelated orogenic systems created during markedly differentiated orogenies (Hall, 1956, p. 2254) but record pulsations of a continuing process of orogeny, by which the original geosynclinal area was being converted into an orogenic system. Flawn's observation shows that the clastic formations are most extensive areally in the salients of the Ouachita Mountains and Marathon region, both in outcrop and subcrop, whereas they form either narrow belts or are missing entirely in the intervening area in Texas. Part of this relation is caused by later structure and erosion, but it suggests that the salients may coincide with the widest and deepest basins of the late geosynclinal stage, and the most vigorously raised tectonic lands, so that a greater volume of clastic sediments accumulated here than elsewhere.

The mass of clastic deposits must have accumulated in a long trough or troughs, so deep that sediments were mostly confined to the troughs except for the youngest deposits in the Atoka formation. Subsidence of the troughs was so rapid that it exceeded the rate of deposition and created areas of deep water, into which much of the coarser material was transported by turbidity currents. Some parts of the sequence have been interpreted as of continental origin, perhaps because of included plant remains and other terrigenous material (Fan and Shaw, 1956, p. 266), but these ideas are as archaic as early notions that graywackes in the Ococe series of Tennessee and the Franciscan formation of California were subaerial piedmont or flood-plain deposits (Barrell, 1925, p. 12; E. F. Davis, 1918, pp. 29–40).

On the contrary, most of the clastic deposits contain flute casts, load casts, groove casts, convolute bedding, graded bedding, and pelagic fossils, and lack cross-bedding, ripple marks, or benthonic fossils—indicating that they accumulated in moderately deep to very deep water (Cline and Shelburne, 1959, p. 206; Cline, 1960, pp. 87–100). In the Ouachita Mountains directional observations indicate movement of sediments westward along the axis of the trough; in the Marathon region no directional observations have been recorded in the Mississippian and Pennsylvanian rocks, but it will be recalled that in the Ordovician rocks Berry (1960, pp. 32–33) has made directional observations which suggest northeastward transport along the axis of the basin.

The Dimple limestone, which interrupts the clastic sequence in the Marathon region, probably expresses merely a cessation of influx of clastic material, rather than shoaling of the bottom. Aside from layers of foraminiferal limestone, most of the strata contain only shell debris and occasional pelagic cephalopods. An apparently analogous facies forms the Chickachoc chert on the margin of the Ouachita geosyncline in Oklahoma, which contains a varied fauna, including abundant sponges. Absence of ripple marks, uniform lamination of the sediments, and the fact that brachiopod valves are still joined indicate that the water in which the Chickachoc accumulated was moderately deep (T. A. Hendricks, written communication, 1960).

The boulder-bearing layers which interrupt the sequence in places are the expectable products of the rapidly deepening troughs. During times of excessive subsidence the margins of the troughs were downflexed and in places faulted. From the submarine scarps thus created, both shelf deposits and blocks of the bedrock slumped or slid into the basin, where they were transported for considerable distances with the aid of turbid flows (P. B. King, 1958, p. 1735).

OROGENIC PHASE (MAINLY PENNSYLVANIAN)

In orogenic systems the late geosynclinal phase blends into the orogenic phase, or the two overlap completely. The orogenic climaxes are commonly interpreted from relations in the marginal parts of the systems, where deformation occurred after that of the inner parts of the systems.

Details of the orogenic phase in the Appalachian system are no longer preserved, but Pennsylvanian coal measures that are infolded with the miogeosynclinal rocks in Alabama and Pennsylvania, and are preserved elsewhere only in the foreland, resemble the molasse of European areas, suggesting that they formed in a very late stage of the orogenic cycle. Credence to this inference is afforded by the many clastic wedges derived from orogenic belts farther southeast which occur in the sequence of middle Paleozoic rocks that underlie the Pennsylvanian in the miogeosynclinal area, and radiometric ages of 280 to 400 million years obtained in the crystalline rocks farther southeast, which suggest that the inner part of the system had been deformed during several orogenies, extending as far back as Middle Ordovician time (P. B. King, 1959, pp. 57–60, 64–65). Although the deformation in the miogeosynclinal and foreland belts was Pennsylvanian or younger, it was marginal to an earlier and greater deformation in the interior of the system.

In the Cordilleran system the frontal parts of the Rocky Mountains were deformed during the Laramide orogeny of Late Cretaceous and Paleocene time, but the record of earlier deformation in the central part of the system is better preserved than in the Appalachians. One or more orogenies during Early Cretaceous and Late Cretaceous time occurred in the western Rocky Mountains and eastern Great Basin (Spieker, 1946, pp. 149–156). Moreover, the Nevadan orogeny of Jurassic time nearer the Pacific Coast, once thought to have created an independent orogenic system, represents merely the orogenic climax in the Cordilleran eugeosyncline.

The record of orogeny is more complete in the Ouachita system than in the Appalachian system, but it is mostly in the marginal parts, where deformation was mainly during Pennsylvanian time but extending in places into Permian time. We will deal mainly with the orogenic record in these marginal parts, although, as indicated earlier, the interior zones of the system were already in process of deformation as far back as later Mississippian time, with still earlier orogenic pulses suggested by minor wedges of clastic rocks in the Silurian and Ordovician.

In the Ouachita Mountains of Oklahoma and the McAlester basin to the north rearrangement of the patterns and environments of the depositional basins began in Atoka time and continued into Des Moines time, probably accompanied by a mounting crescendo of orogeny within the present mountain area.

The total thickness of the Atoka formation that was originally deposited over the site of the Ouachita Mountains is unknown, but the 19,000 feet preserved along the mountain front may have been near the depositional maximum. The formation thins rapidly northward and northwestward from the mountain front toward the Ozark and Hunton uplifts, passing from a deep-water geosynclinal deposit into a mixed shallow-water and nonmarine deposit less than 500 feet thick. Disturbances must have occurred in the Ouachita Mountains during Atoka time, as in places in the mountains the Atoka is unconformable on underlying formations, and as west of the mountains it contains beds of chert conglomerate.

No Pennsylvanian rocks younger than the Atoka are preserved within the Ouachita Mountains, but strata of Des Moines age are as much as 7,000 feet thick in the McAlester and Arkansas basins immediately to the north, where they are sandstones and shales, with many coal beds. According to Hendricks (written communication, 1960), "Turbidites occur not only in the Atoka, but in the McAlester and Savanna formations. Marine fossils which have been collected from them include more than 30 species and numerous individuals, whose shells are characteristically still joined. Much of the deposition must have been in fairly deep water, and the basin filled up to sea level only at times of coal deposition."

Absence of beds of Des Moines age from the Ouachita Mountains is probably not merely an accident of erosion, as that area was probably in process of deformation. From Stanley and Jackfork time, through Atoka time, into Des Moines time the axis of the depositional trough shifted from the interior of the mountains to its margin, and thence into the foreland area beyond. The depositional environment also changed progressively to shallower water, with occasional coal swamps toward the end.

Deformation thus presumably began in the Ouachita system during Atoka time and continued through Des Moines time. Moreover, the Des Moines strata in the McAlester and Arkansas basins are thrown into linear folds parallel with those in the Ouachita Mountains that diminish in intensity outward to the north and northwest, indicating that thrusting from the Ouachita area continued even later. During these times of deformation, the Ouachita rocks were extensively thrust toward their foreland—probably on the order of 50 miles in the western part of the exposed area (Hendricks, 1959, p. 55). Flawn (1959a, p. 2013) suggests that there was also lateral movement of the Ouachita rocks on transverse faults at the sides of the Arbuckle massif in subcrop which was on the order of 30 miles (p. 171).

The inferred deformational history in the Ouachita Mountains area is probably representative of much of the salient of the Ouachita system between Mississippi and central Texas, but in the salient to the west, centering in the Marathon region, deformation apparently reached its climax later.

Strata which accumulated near the time of the orogenic climax are exposed in two areas in the Marathon region, but these areas exhibit strangely contrasting histories:

In the northeastern Marathon Basin, near the type areas of the Wolfcamp and Gaptank formations, the characteristic clastic deposits of the Haymond formation are succeeded by the more varied Gaptank and Wolfcamp deposits, formed in a shallower, less stable marine environment. Many conglomerate beds in the middle of the Gaptank contain water-worn cobbles not only of the Dimple limestone and other older formations but also of the basal limestone member of the Gaptank itself. They record the first strong pulse of orogeny in the exposed part of the Marathon region and are approximately of Missouri age, or younger than any of the orogenic sediments in the Ouachita Mountains region. Nevertheless, the exposed sequence of Haymond, Gaptank, and Wolfcamp formations seems to be structurally conformable, despite ubiquitous local channeling at many levels, so that the steep folding of the Haymond passes gradually northward into the gentle tilting of the upper part of the Gaptank and the Wolfcamp. The first decided unconformity is at the top of the Wolfcamp formation as defined, at what has been called the base of the Leonard series, although it is now known that the zone of *Pseudoschwagerina* extends above it (C. A. Ross, 1959, p. 300).

In the northwestern Marathon Basin the later Pennsylvanian, mapped as Gaptank and Haymond formations, is a thick mass of highly deformed shale and of thin layers of sandstone, sandy limestone, and chert-pebble conglomerate. More than 6,600 feet of similar strata were drilled through in the Slick-Urschel No. 1 Decie well before entering older rocks. These strata are so different from the type Gaptank that it is hardly surprising that they were assigned to the Tesnus formation during the first survey (Baker and Bowman, 1917, pp. 104–105); like the Tesnus they were probably deposited in water of much depth in a rapidly subsiding trough, rather than on an unstable shelf. Nevertheless, fossils from many localities indicate a wide range of later Pennsylvanian ages (Des Moines, Missouri, and Virgil) (P. B. King, 1937, pp. 80–82), and all the clastic strata in the Decie well have been assigned to the Wolfcamp (Hall, 1956, pp. 2253), perhaps because they include part of the zone of *Pseudoschwagerina*.

The Decie well demonstrates that these strata overlie a foreland sequence of older Paleozoic rocks like that beneath the West Texas basin. Moreover, field relations show that they are overridden from the southeast for many miles along the Dugout Creek thrust by a plate of older Paleozoic rocks of the Ouachita sequence, a relation confirmed by the Decie well and the Gulf Oil Corporation No. 1 D. S. C. Coombs well farther southeast, both of which drilled through the plate into the overridden rocks. Both overridden and overriding rocks are overlain on the north by the Wolfcamp formation, with great angular unconformity and coarse basal conglomerate, thus establishing the culmination of deformation and thrusting as within the early part of the zone of *Pseudoschwagerina*.

The strata in the northwest part of the Marathon Basin are an exposed fragment of a much more extensive mass of deposits, laid down in a foreland trough that extends eastward beneath the surface, north of the Marathon region and into the Val Verde basin of Terrell and Val Verde counties (Galley, 1958, pp. 424–428). There, as much as 14,000 feet of Late Pennsylvanian and Early Permian clastic rocks have been reported, the greater part of which have been called Wolfcamp. Along at least part of its length, the trough must be overridden from the south by thrust plates of rocks of the Ouachita system, comparable to the plate above the Dugout Creek thrust in the exposed area.

In this setting, the relatively thin sequence of shallow-water deposits of the type Gaptank and Wolfcamp formations in the northeastern Marathon Basin is anomalous. However, this sequence lies within the Ouachita system rather than in the foreland, and the deep foreland trough filled by contemporaneous deposits must lie north of it. The environment in which the sequence accumulated was a product of an earlier orogenic pulse of Missouri age, which destroyed the deep basins within the Ouachita system that had existed during Haymond and earlier times and converted the marginal part of the system into a geanticline or unstable shelf, covered only by shallow seas.

This review demonstrates that in each segment of the Ouachita system the belts of deformation and deposition migrated with time from the inner part of the system toward its foreland. The review also suggests that the climactic orogeny in the Ouachita system migrated westward with time—the orogeny in the salient centering in the Ouachita Mountains being of Middle Pennsylvanian age, and that in the salient centering in the Marathon region being of Late Pennsylvanian and Early Permian age. This westward migration may also have extended into the little-known prolongation of the Ouachita system in Mexico, where the Permian includes thick accumulations of graywacke, other clastic rocks, and volcanic rocks, and where some of the Permian sequences (as that near Las Delicias, Coahuila) were strongly deformed late in Permian time or shortly thereafter.

POST-OROGENIC PHASE (PERMIAN AND LATER)

Modern surface features of the mountain belts around the borders of North America were created during the post-orogenic rather than the orogenic phase. Even in the Cordilleran system, where the orogenic phase persisted later than in the other systems, the rugged mountains are products of the succeeding heterogeneous local orogenies, or of the final epeirogeny. In the older Appalachian system the mountains are products of epeirogeny and are erosional remnants in areas of regional uplift. Even greater areas in the Appalachian system have regionally subsided, have been buried by younger sediments, or have been lost beneath the sea (P. B. King, 1959, pp. 41–42; Billings, 1960, pp. 376–380). In the Ouachita system, epeirogenic uplift has been less extensive than in the Appalachian system, so that no more than 275 miles of its length is now exposed, out of an original thousand or more—in the Ouachita Mountains, the Marathon dome, and a few smaller areas. Regional subsidence has been much more extensive; the inner part of the system, especially, has been peculiarly susceptible to collapse, so that most of it is deeply buried by the Mesozoic and Cenozoic deposits of the Gulf Coastal Plain.

Late Paleozoic post-orogenic deposits are extensive in the continental interior of the south-central states, especially near the uplifts of the Wichita system. In Oklahoma they are largely of continental origin and include the Late Pennsylvanian conglomerates of the Pontotoc group that overlap the Arbuckle Mountains, and the Permian red beds that half-bury the Wichita Mountains. In west Texas, where marine conditions persisted through Permian time, the uplifts are masked and buried by carbonate deposits, including extensive reefs.

Except in the Glass Mountains, along the northern edge of the Marathon region, few of the post-orogenic deposits of the continental interior extend onto the deformed rocks of the Ouachita system. However, within the inner part of the system some wells have passed from strata of proved Mesozoic age into undisturbed shales, red beds, and coarser clastic rocks, whereas adjacent wells have entered thoroughly deformed and metamorphosed rocks of Ouachita facies (*see* "Post-orogenic Paleozoic rocks lying on the Ouachita belt," pp. 125–127). Some of the undisturbed rocks are certainly Paleozoic, as invertebrate and plant fossils of Pennsylvanian and Early Permian age have been identified in them in Morehouse Parish, northern Louisiana, and in Bexar and Frio counties, central Texas. Some of the others, from which no fossils have been obtained, might be of early Mesozoic age, like the Triassic Newark group of the inner part of the Appalachian system. The most extensive of these undisturbed rocks are the unfossiliferous red beds of the Eagle Mills formation, classed doubtfully as of Permian age, which have been penetrated in many wells along the south flank of the Ouachita Mountains from southern Arkansas into northeastern Texas. The other undisturbed rocks are recorded only in single wells, so that nothing can be told of their structural relations. By analogy with late Paleozoic post-orogenic deposits of the northern Appalachians (in the Maritime Provinces of Canada) those of the inner part of the Ouachita system might have formed in local basins of various sizes, between ridges of deformed earlier rocks.

Perhaps only sometime after these strata had been deposited were the modern uplifts and depressions within the Ouachita system differentiated. In the continental interior, and along the margins of the Ouachita system, Lower Cretaceous strata lie on a deeply eroded, truncated, and peneplaned surface of the Paleozoic rocks—the Wichita paleoplain of Hill (1901, p. 363) —which had been perfected during earlier parts of Mesozoic time. This surface may combine effects of several periods of erosion in the inner part of the Ouachita system, as various unconformities are recorded between and beneath the Jurassic and Cretaceous rocks in the Gulf Coastal Plain.

Exposures of the Ouachita system in the Ouachita Mountains result from epeirogenic uplift. Within the mountain area is a large and abrupt gravity minimum of more than 100 milligals, caused, probably, by a great thickness of light sediments, even now uncompensated, which have been rising since the orogenic climax. Ridge-crest profiles of the mountains suggest the existence of a former Ouachita peneplain (Miser and Purdue, 1929, pp. 136–139), which is seemingly traceable southward into the Wichita paleoplain beneath the Lower Cretaceous strata of the coastal plain. However, uplift of the Ouachita Mountains is more complex than thus suggested, as Upper Cretaceous rocks south of the mountains bevel Lower Cretaceous rocks eastward, and as both these and the deformed Paleozoic rocks of the Ouachita system are beveled in turn near Little Rock, Arkansas, by Paleocene and Eocene rocks of the Mississippi embayment.

In the Marathon region, uplift of the rocks of the Ouachita system was probably more orogenic than epeirogenic. A deficiency of gravity occurs here, probably due to excessive thickness of light sediments as in the Ouachita Mountains, but this is a rather minor feature. Lower Cretaceous rocks perfectly truncate the Paleozoic structures along the Wichita paleoplain, but this was not distorted until after Cretaceous time. The Marathon dome, in which rocks of the Ouachita system are exposed, was produced primarily by resistance offered by the transverse-striking Ouachita structures to compression from the west during the Cordilleran orogenies. The dome was raised during at least two periods, near the end of the Cretaceous and early in the Tertiary (P. B. King, 1937, pp. 139–140).

Subsidence of the remaining part of the Ouachita system began primarily in Mesozoic time and was accentuated during Cenozoic time. The first extensive deposits over the inner part of the system comprise the Werner formation and Louann salt—the latter the source of the salt domes over much of the Gulf Coastal Plain—which are probably younger than the Eagle Mills formation (Hazzard et al., 1947, p. 483). The Werner and Louann have been called Permian, like the Eagle Mills, but are more likely the first deposits of the Mesozoic transgression (McKee et al., 1956, pp. 1–2). They are followed by a great sequence of Upper Jurassic and Lower Cretaceous rocks, only the highest of which persist updip to the outcrop, and these by the Upper Cretaceous and Tertiary.

The area of subsidence corresponds to the Gulf Coastal Plain and is related to differentiation of the Gulf of Mexico as a tectonic feature. Nevertheless, as indicated earlier by Miser (1934c, pp. 1067–1072), the inner edge of the area of subsidence, from Texas eastward to Mississippi, corresponds remarkably to the marginal part of the Ouachita system. Zones of normal faulting along the edge of the area of subsidence, such as the Balcones fault zone of Texas and others farther east, and zones of igneous activity of Cretaceous and early Tertiary age, closely follow the Ouachita trend. This relation may be coincidental, but at the very least, the structures associated with the subsidence of the Gulf of Mexico utilized lines of weakness already created by the Ouachita system. More likely, the Ouachita system and the Gulf of Mexico are manifestations of a single continuing process, the structural features of the latter being inherited from those of the former.

Economic Possibilities

AUGUST GOLDSTEIN, JR., and PETER T. FLAWN

General Statement

From an economic point of view, the Ouachita structural belt is the least known and most poorly understood structural trend in the southern United States; it is a 1,300-mile long nonproductive swath which is flanked by areas of large oil and gas production and reserves in the coastal plain to the south and east and in the basins to the north and west. Miser (1934c) has emphasized how the Ouachita structural belt separates the Paleozoic production of the Mid-Continent region on the north and west from the Mesozoic and Tertiary production on the south and east. Most of the data and conclusions in this chapter are taken from an earlier paper by Goldstein and Flawn (1958).

Most petroleum geologists have considered the rocks of the Ouachita structural belt as being highly metamorphosed, and the trend is commonly called the "schist" belt. Of the more than 200 wells which have encountered the rocks of the structural belt, most have been abandoned after penetrating only a short section of rocks of Ouachita facies, largely because the rocks were regarded as metamorphosed and unsuitable for oil and gas reservoirs. Medium to high-grade metamorphic rocks have been encountered in a few wells, but in others the so-called "schist" is actually highly sheared and contorted shale. "Black granite" reported from north-central Texas wells is a local name for steeply dipping black shales of the structural belt; this cognomen certainly tends to discourage deeper drilling.

In addition to the rather limited vertical penetration of the rocks of the structural belt, the average drilling density along the entire structural belt is so thin that the belt as a whole must be classified as unexplored.

There are two possible petroliferous provinces associated with the Ouachita structural belt. Although related tectonically, they differ widely in lithology and environment of deposition and require entirely different exploration techniques and "exploration thinking" for proper evaluation of their petroleum possibilities. There are, first, the possibilities of oil and gas production in the rocks of Ouachita (geosynclinal) facies and, second, the petroleum potentialities of the rocks of foreland (Arbuckle or "normal") facies both underlying and adjacent to the fold-belt.

POSSIBILITIES OF PETROLEUM PRODUCTION IN ROCKS OF OUACHITA FACIES

In the western part of the Ouachita Mountains of Oklahoma, the northern limit of the Ouachita Mountains is generally considered to be the Choctaw fault. A wide variety of rocks of Ouachita facies ranging in age from Cambrian(?) to Atokan occur from the Choctaw fault southward to where the Ouachita Mountains are overlapped by Cretaceous sediments. Paleozoic beds in this area are not all metamorphosed—some show practically no alteration. At other places, the rocks show intense crushing, contain numerous quartz veinlets, and are recrystallized due to metamorphism. These latter areas are unfavorable for petroleum production; limited data suggest strongly that the oil is dissipated long before any observable metamorphic changes occur. Furthermore, it is probable that reduction or virtual elimination of pore space in potential reservoir beds occurs very early in low-grade regional metamorphism, possibly before there are any positive microscopic indications of mineralogical changes due to metamorphic reorganization.

In the areas of the Ouachita Mountains where rocks are essentially unmetamorphosed, there seems to be no reason why it is not possible to find reservoirs of oil and gas. There is considerably more reason to doubt that these deposits will be economically profitable except under unusual circumstances. Most of the potential reservoir beds are in the sandstones of the Stanley, Jackfork, and Atoka formations. These rocks typically have low porosity and very low permeability. Local development of fracture porosity possibly could create suitable reservoir rocks out of these tight argillaceous sandstones. The quartzose sandstones of the Crystal Mountain and Blakely occur mostly in the more metamorphosed terranes of the Ouachita Mountains and cannot be regarded as suitable reservoir beds on the basis of their observed properties where they crop out. The Blaylock sandstone is both generally tight and very limited in its areal distribution. The sandstone development in the Womble occurs in the more highly metamorphosed portion of the Ouachita Mountains, and the Womble is largely shale in the unmetamorphosed areas.

Structurally, the conditions for trapping oil and gas are not very favorable. Large faulted anticlines are present in the Ouachita Mountains, and presumably there are large anticlinal structures in the buried rocks of the foldbelt. However, it will be difficult to locate and map closed structural traps in these rocks. Moreover, the numerous faults provided a means for escape of oil and gas.

Nevertheless, a completely pessimistic approach to the petroleum possibilities in rocks of Ouachita facies seems unwarranted. Oil has been produced from shallow wells in Stanley sandstone near Redden, Atoka County, Oklahoma. These wells, originally drilled as early as 1914, produce at a depth of 500 feet from steeply dipping, tight sandstone sealed up-dip by asphalt impregnation. The amount of production obtained and the periods during which the wells have produced are not known to the writers. The oil at Redden may have migrated from some of the older, more petroliferous, underlying rocks that were faulted against sandstones of the Stanley.

Hendricks et al. (1947), Ham (1956a), and Howell and Lyons (1959) reported on the many oil seeps and veins and irregular bodies of grahamite or asphaltite (solid hydrocarbon) within the Ouachita Mountains. It has been suggested that the petroleum in the seeps and that which formed the grahamite probably originated in the strata of foreland facies underlying the overthrust beds, and that this oil subsequently migrated into rocks of Ouachita facies.

Oil-stained sandstones and scattered noncommercial gas shows have been observed in Stanley-Jackfork strata penetrated by deep wells in the Ouachita Mountains of Oklahoma. In some wells the beds with oil or gas shows overlie thousands of feet of Ouachita facies rocks, and the hydrocarbons are unquestionably indigenous rather than derived from underlying rocks of foreland facies. In the subsurface Ouachita structural belt in Texas, small amounts of asphaltic material are fairly common in sandstones and cherts.

A possible approach to this problem is to concentrate exploratory efforts in unmetamorphosed areas with large structures (to drain as large an area as possible), where massive thick beds of sandstone are present at shallow depths (to make up for generally low porosity and permeability). Only under such conditions would oil or gas deposits in sediments of Ouachita facies prove to be economically attractive.

POSSIBILITIES OF PETROLEUM PRODUCTION IN ROCKS OF FORELAND FACIES UNDERLYING OR ADJACENT TO THE OUACHITA STRUCTURAL BELT

Evaluation of the possibilities of petroleum production in rocks of *foreland* facies underlying or adjacent to the Ouachita structural belt involves a number of factors. Among these factors are the validity of the carbon ratio theory, relative proximity to the foldbelt front, geologic section present, age, intensity, and nature of the structural movements, and productive history of the adjoining area.

There are a number of reasons why the oil production possibilities of these foreland rocks have not been tested adequately heretofore.

(1) Most wells that have been drilled on structures associated with or involved in the frontal zones of the orogenic belt have encountered a high degree of secondary silicification in pre-Atokan sandstones. This silicification is coincident with high carbon ratios in coals of the overlying Des Moines series. If a fixed carbon ratio in excess of 62.5 is considered to be the limiting parameter for oil production, the studies by Fuller (1919) and Hendricks (1935) appear to condemn for oil production part of the frontal area adjacent to the Ouachita structural belt.

(2) Because of the complexity of the highly faulted and strongly folded areas adjacent to the foldbelt front, conventional subsurface geologic and geophysical methods of exploration are of limited value.

(3) Most of the drilling for prospects adjacent to the structural belt, and all of the drilling for prospects underlying thrust sheets, requires deep wells. Drilling of thick sections of steeply inclined beds of hard shale and quartzitic sandstone presents many problems, such as excessive well deviation and use of numerous bits; well costs in this area are high.

(4) Statistical compilations such as those by Knebel and Rodriquez-Eraso (1956) and the classic study of Weirich (1953) suggest that the stable (shelf) side of a basin contains more oil than the mobile side.

(5) Some geologists believe that the oil and gas found in Ellenburger and Arbuckle reservoirs had its source in Mississippian or Pennsylvanian beds of foreland facies, and that exploration is not justified unless these late Paleozoic "source beds" are in contact with the older Paleozoic carbonate rocks.

These arguments make it clear why large sums of money have not been allotted to exploration for oil in rocks of foreland facies immediately adjacent to or underlying the Ouachita structural belt. Some of these arguments are still valid today, but others deserve re-examination.

There is serious doubt that carbon ratios derived from coals of Desmoinesian age have any meaning when applied to the underlying sedimentary rocks of lower Paleozoic age. Most of the major Ouachita Mountains overthrusts (sole thrusts) in the frontal area follow closely along the bedding of incompetent shale which acted as a lubricant. Dynamic metamorphism due to this movement is restricted to a relatively narrow zone adjacent to the thrust plane. (*See* David Young (1957) for a discussion of the thrust zone at the base of the Cumberland block in the Appalachian area.) Underlying sediments of foreland facies should not be considered as metamorphosed simply because of superjacent thrust faulting. Secondary silica cementation of quartzose sandstones, such as those of the Simpson group ("Wilcox"), may be purely a sedimentary process not related to metamorphism. Porosities in Simpson sandstones encountered in deep wells in

Coal and Atoka counties, Oklahoma, have been generally adequate in wells drilled close to the frontal zone of the Ouachita Mountains, and some production has been obtained. However, this is not an area of high carbon ratios, and oil production in these counties does not prove or disprove any lack of relationship between high carbon ratios in Des Moines beds and silicified lower Paleozoic sandstones. It is considered probable, however, that deep Ordovician production (Simpson, Ellenburger-Arbuckle) will be obtained eventually from areas of high carbon ratios adjacent to the frontal orogenic zone.

High well costs and lack of satisfactory exploration methods are merely challenges to oil men, not insurmountable barriers. No one doubts that they can be overcome if enough drilling is done. After a number of rank wildcat tests have provided a base of general stratigraphic and structural information, geophysical data interpreted by geologists experienced in the geology of folded and thrust-faulted mountains should provide a more scientific basis for prospecting.

Statistical compilations of the production on the mobile and stable parts of a basin may be misleading. The mobile side of a basin is much more difficult to prospect than the stable side, and the drilling density on the stable side is usually much greater. Entrapment of oil and gas along an orogenic front is in no way unusual; many fields in different parts of the world produce from rocks involved in Appalachian or Alpine-type deformation.

Condemnation of the vast area along the front of the Ouachita structural belt on the basis of the theory that oil and gas can only be found where Mississippian or Pennsylvanian source beds overlie directly the Ordovician carbonate rocks seems completely unwarranted to the writers. This theory is regarded as not proven, but even if it were correct it could not be used to condemn the frontal zone of the Ouachita belt because of the complex stratigraphic and structural conditions which obtain there. It can be reasonably expected that almost every possible source bed could be in contact with a possible reservoir bed at some place along the structural belt.

It is difficult, except in a very general way, to select parts of the Ouachita belt as more favorable for prospecting than others because of the lack of any significant amount of exploratory drilling. Studies of the belt indicate that the trace of the buried front is not a continuous straight line but is marked by salients, recesses, and allochthonous plates (Pl. 1). Each local area must be considered separately on its own merits. The segments of the belt which have been crushed against the Llano and Devils River buttresses do not appear to be favorable because of the severity of the deformation. Compared to this area, the frontal zone of the Ouachita Mountains and the adjacent McAlester basin structures appear to be excellent places for further exploratory drilling. Frontal zone structures in the Fort Worth, Kerr, and Val Verde basins and in the Sheffield channel likewise seem relatively promising. In Collin and Grayson counties of north Texas, in Bell County in central Texas, and in the northern part of the Marathon Basin in Brewster County, Texas, wells have penetrated large thicknesses of unmetamorphosed rocks of foreland facies beneath overthrust Ouachita facies rocks.

In prospecting Ordovician carbonate facies rocks (Arbuckle-Ellenburger) along the Ouachita front, three factors should be considered: (1) the change in carbonate lithology from foreland to deep trough, (2) the amount of structural displacement of the Ouachita facies rocks, and (3) post-Ordovician downwarping of the foreland section. It is generally true that carbonate rocks on foreland shelves include permeable dolomites which make excellent reservoirs, whereas the carbonate rocks deposited in deep troughs are dense fine-grained unfossiliferous rocks without significant reservoir capacity. If Ouachita facies rocks have been thrust over shelf facies carbonate rocks, oil prospects are good; there is a possibility, however, that wells drilled some distance back of the front may penetrate the Ouachita facies only to encounter dense fine-grained Ordovician carbonate rocks unsuitable for the accumulation of oil and gas.

CONCLUSIONS

Oil possibilities of rocks of foreland facies underlying or adjacent to the Ouachita structural belt are far superior to the oil possibilities of rocks of geosynclinal facies. These foreland rocks have produced tremendous quantities of oil in Texas and Oklahoma. They have been thoroughly explored in much of their normal area of deposition, and the opportunity for major "oil finds" lessens as more and more deep tests are drilled and the untested areas diminish. The widespread occurrence of these foreland rocks in and adjacent to the Ouachita structural belt and the lack of adequate exploration to date make this area one of the largest remaining untested, possibly petroliferous, provinces in the southwestern United States.

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Appendix

PART 1. SUMMARY REPORTS ON WELLS PENETRATING ROCKS OF THE OUACHITA BELT AND IMMEDIATELY ADJACENT FORELAND IN TEXAS

PETER T. FLAWN

Information on the following wells was compiled from many different sources. Few of the data were available in published material. The bulk of the basic well data and stratigraphic data was taken from the files of operating companies and from the files of the Bureau of Economic Geology. Except where credited to another source, all of the petroraphic data are original. All of the X-ray determinations were made by C. E. Weaver.

The following symbols and ratios are used to express X-ray data: K=kaolinite; Ch=chlorite; I=illite; M=montmorillonite; ML=mixed layer illite-montmorillonite; F=20=plagioclase feldspar; F=24=potassium feldspar; SR=sharpness ratio; 10/7= ratio of height of illite X-ray peak (10Å) to the combined (if both are present) chlorite and kaolinite (7Å) X-ray peak

Ni means that no information was available.

County.—Bandera.

Well name.—General Crude Oil Company No. 1 Anderson.

Location.—Section 21, GH&SA survey; 3,245 feet FNWL, 300 feet FNEL; 25 mi. NW of Bandera.

Elevation.—1,843 feet, derrick floor. *Total depth.*—10,626 feet. *Completed.*—1955.

Top of Paleozoic rocks.—1,097 feet. *Elevation of Paleozoic rocks.*—+746 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 3040–50.

Description of Paleozoic rocks.—The well penetrated a normal foreland basin sequence north of the Ouachita structural belt. Top of Ordovician is 7,500 feet (Barnes, 1959). The sample from 3,040–3,050 feet is a dark, bentonitic silty shale which indicates the presence of volcanic material in the sequence.

X-ray data.—$I > ML > Ch > K$; $10/7 \sim 1.5$; $F = .20$.

References.—Barnes (1959, p. 334).

County.—Bandera.

Well name.—Humble Oil & Refining Company No. 1 Thompson.

Location.—J. A. Delgado survey; 750 feet N, 2,500 feet E of SW cor. of Thompson 934 acres.

Elevation.—1,660(?) feet. *Total depth.*—3,670 feet. *Completed.*—1924.

Top of Paleozoic rocks.—800 feet. *Elevation of Paleozoic rocks.*—+860(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Paleozoic rocks encountered in this well are considered to be Upper Mississippian and Lower Pennsylvanian; no reliable subdivision has been made (Woods, 1957).

This well is probably north of the Ouachita structural belt in foreland basin rocks. No samples were examined.

X-ray data.—None.

References.—Personal communication: R. D. Woods, Humble Oil & Refining Company, 1957.

County.—Bandera.

Well name.—H. L. McBride No. 1 Fee.

Location.—J. F. Davenport survey; NW cor. on Privilege Creek, 4 mi. NE Bandera.

Elevation.—1,345 feet, derrick floor. *Total depth.*—11,050 feet. *Completed.*—1952.

Top of Paleozoic rocks.—870 feet. *Elevation of Paleozoic rocks.*—+475 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Two core fragments from the interval 870 to 1,179 feet are strongly deformed and fractured dark shale veined by carbonate.

This well seems to have penetrated Mississippian-Pennsylvanian rocks of Ouachita facies in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Robert Pavlovic, Magnolia Petroleum Company, 1959.

County.—Bandera.

Well name.—Mikton No. 1 Stelzer.

Location.—H. E. Rogers survey; 1,650 feet FEL, 2,800 feet FSL; 1.5 mi. FW, 7.1 mi. FS County line.

Elevation.—1,742 feet, derrick floor. *Total depth.*—8,515 feet. *Completed.*—1952.

Top of Paleozoic rocks.—1,040 feet. *Elevation of Paleozoic rocks.*—+702 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Young (1957) reported base of Cretaceous at 1,040 feet; the sequence from 1,040 feet to total depth consists of alternating gray shale and sandstone. These rocks are probably all Pennsylvanian, but it is possible that the upper part of the sequence includes Wolfcamp beds.

This well is north of the Ouachita structural belt in foreland basin rocks.

X-ray data.—None.

References.—Personal communication: Addison Young, Phillips Petroleum Company, 1957.

County.—Bandera.

Well name.—Plateau (Peerless) Oil Company No. 1 R. D. Garrison.

Location.—Section 506, GC&SF survey; 2,900 feet FNL, 1,900 feet FWL; 9 mi. NW of Tarpley.

Elevation.—1,835 feet. *Total depth.*—5,365 feet. *Completed.*—1935.

Top of Paleozoic rocks.—1,150 feet. *Elevation of Paleozoic rocks.*—+685 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 1220–40, 1381–98, 1440–44, 2186–87, 2224–25, 2400–20, 2510–12, 2588–90, 2674–77, 3160–80, 3200–07, 3750–70, 3790–3810 (2), 3830–50, 4610–30, 5090–5110, 5130–50, 5230–50. SHELL OIL COMPANY: 1160–80.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology indicate base of Cretaceous at 1,150 feet and describe the sequence between 1,150 and 5,365 feet, total depth, as dark gray, greenish-gray, reddish-brown, and light green schistose shales with thin streaks of gray quartzitic sandstone and quartzite cut by quartz and calcite veinlets; the upper part of the sequence is red due to weathering.

This well penetrated a sequence of dark, angular, poorly sorted, chloritic micaceous siltstone and dark silty shale with lesser amounts of fine-grained, angular to subangular, poorly sorted, micaceous chloritic feldspathic quartz sandstone and dark, pyritic argillaceous cryptocrystalline to microgranular chert; locally the rocks are extensively invaded by chlorite-quartz-calcite veinlets. Some of the quartz veinlets contain bitumen.

The entire sequence shows varying degrees of metamorphism, mostly incipient but ranging up to very weak and weak in some intervals; 1,160–1,180-foot interval is composed of silty sericite-chlorite clay-slate and sericitic chloritic metasiltstone; 3,830–3,840-foot and 4,610–4,630-foot intervals are composed of sericite-chlorite slate and chloritic micaceous metasiltstone; the slate with "hourglass" carbonate porphyroblasts is similar to that seen in Turner No. 1 Linder in Kendall County, Blumberg No. 1 Knibbe and Newton No. 1 Check Ranch wells in Comal and Kendall counties, and other wells to the northeast (p. 66).

This well is close to the northern limit of the Ouachita belt, and the degree and variation of metamorphism suggest folding and possibly thrusting along this frontal segment of the belt. (*See* Blumberg No. 1 Knibbe, p. 243.) Such advanced metamorphism and extensive veining are not common along the frontal margin of the belt to the west or along the course of the belt north of the Llano uplift. The rocks penetrated in this well are interpreted as upper Paleozoic Ouachita facies overlying lower Paleozoic Ouachita facies, but possibly the entire sequence is lower Paleozoic.

An interpretation suggested by Maner (1958) is that the sequence is composed of Stanley beds overlying Atoka beds containing abundant detritus from early and middle Paleozoic Ouachita facies rocks; according to this hypothesis, slightly metamorphosed pre-Stanley Ouachita facies rocks somewhere to the south were uplifted (by thrusting?) to form a provenance for Atoka detritus and subsequently the Atoka beds were overthrust by Stanley rocks.

X-ray data.—None.

References.—Goldstein and Reno (1952, fig. 10-B, p. 2283).
Bureau of Economic Geology files.
Personal communication: R. P. Maner, Shell Oil Company, 1958.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bandera.

Well name.—Ray Pool Drilling Company No. 1 E. L. Rainey.

Location.—Section 16, GH&SA survey; 2,600 feet FSWL, 1,500 feet FNWL.

Elevation.—1,737 feet. *Total depth.*—5,009 feet. *Completed.*—1947.

Top of Paleozoic rocks.—1,000± feet. *Elevation of Paleozoic rocks.*—+737± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—A sample log shows that the well penetrated Paleozoic rocks at 1,020 feet (Sandidge, 1957).
This well is probably in foreland basin rocks north of the Ouachita structural belt.

X-ray data.—None.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Bandera.

Well name.—Rossman (Stan-Ross) No. 1 Goodenough.

Location.—J. B. Gobles survey; 660 feet FSWL, 660 feet FSEL; 2½ mi. NE of Bandera.

Elevation.—1,347 feet. *Total depth.*—5,508 feet. *Completed.*—1953.

Top of Paleozoic rocks.—840 feet. *Elevation of Paleozoic rocks.*—+507 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 855–58 (2), 1245–50, 1425–30, 2245–50 (2), 2470–75 (2), 3590–3600 (2), 4080–90 (3), 5490–5500.

Description of Paleozoic rocks.—The sequence is composed of angular to subangular, poorly to fairly well-sorted, micaceous chloritic argillaceous feldspathic quartz sandstone and dark, carbonaceous silty shale and metashale, both commonly invaded by quartz veinlets; the sandstones contain abundant rock fragments, mostly phyllite. Locally the sandstones are dolomitic. The sequence is composed of upper Paleozoic Ouachita facies rocks; metamorphism varies from none to incipient.
This well is in the frontal zone of the Ouachita structural belt.
The writer was unable to identify individual units in this sequence; Maner (1958) suggested that the sequence is composed of Stanley beds thrust over Atoka and compared it to the section penetrated in Plateau No. 1 Garrison (p. 212).

X-ray data.—I > Ch; $10/7 \sim 0.8$; $F = 20$; $SR = 3.2$.

References.—Personal communication: R. P. Maner, Shell Oil Company, 1958.

County.—Bandera.

Well name.—G. L. Rowsey No. 1 Fee.

Location.—Section 3, BS&F survey; 1,080 feet FWL, 1,384 feet FSL; 8 mi. NE of Bandera.

Elevation.—1,757 feet, derrick floor; 1,747 feet, ground. *Total depth.*—6,200 feet. *Completed.*—1954.

Top of Paleozoic rocks.—940 feet. *Elevation of Paleozoic rocks.*—+817 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Information from scout cards indicates top of Ellenburger, 4,412 feet and top of Hickory, 5,750 feet. These data indicate that the well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—None.

County.—Bandera.

Well name.—G. L. Rowsey No. 2 Fee.

Location.—J. M. Shipp survey; 1,120 feet W and 550 feet N F SW cor. of BS&F survey; 10 mi. NW of Bandera.

Elevation.—1,809 feet, derrick floor; 1,798 feet, ground. *Total depth.*—6,970 feet. *Completed.*—1953.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Scout card reports top of Marble Falls, 4,000 feet; top of Ellenburger, 4,495 feet; top of Hickory, 6,833 feet. The well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1959, p. 341).

County.—Bandera.

Well name.—G. L. Rowsey No. 5 Fee.

Location.—J. M. Shipp survey; 4,000 feet F most N'ly NL, 330 feet F most N'ly EL; 10 mi. NNW of Bandera.

Elevation.—1,848 feet. *Total depth.*—5,069 feet. *Completed.*—1958.

Top of Paleozoic rocks.—1,000± feet. *Elevation of Paleozoic rocks.*—+848± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1,700±.

Description of Paleozoic rocks.—Information from scout card indicates top of Marble Falls, 4,738 feet; top of Ellenburger, 4,960 feet. The single sample available for study is a dark, carbonaceous silty shale veined with quartz, probably Atoka. This well penetrated foreland basin rocks north of the Ouachita belt; quartz veins in the Atoka(?) shale suggest proximity to the front of the Ouachita belt.

X-ray data.—None.

References.—None.

County.—Bandera.

Well name.—Wood Texas Oil Company No. 1 A. E. Clayton (also carried as H. W. Clayton).

Location.—GM&D survey; ¾ mi. N of Vanderpool.

Elevation.—1,900 feet (from topographic map). *Total depth.*—4,020 feet.

Completed.—1920(?).

Top of Paleozoic rocks.—960 feet. *Elevation of Paleozoic rocks.*—+940 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology are as follows: top of Pennsylvanian, 960 feet; top of Ellenburger, 4,020± feet; the Pennsylvanian sequence is composed of gray slickensided sandstone and quartzitic sandstone and dark to black, slickensided shale; quartz veins are rare. Although the top of Ellenburger was identified in this well, there is nothing in the sample descriptions to substantiate the determination.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Bandera.

Additional well not shown on map (Pl. 2) and not studied because of lack of samples or basic data:

G. L. ROWSEY NO. 1 GUS EVANS—

Location: George Ball survey; 330 feet FNEL, 330 feet FNWL; 6 mi. N of Bandera. *Elevation:* 1,397 feet, derrick floor; 1,389 feet ground. *Total depth:* 6,500 feet. *Completed:* 1958. *Top of Paleozoic rocks:* 770 feet (Pennsylvanian sand).

County.—Bastrop.

Well name.—Skelly Oil Company and Sunray Midcontinent Oil Company No. 1 Itha Ray.

Location.—Ed. Gritten survey; 330 feet F Caldwell County line, 2,500 feet F Travis County line.

Elevation.—605 feet. *Total depth.*—3,928 feet. *Completed.*—1956.

Top of metamorphic rocks.—3,720 feet. *Elevation of metamorphic rocks.*— −3,115 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3750–75, 3800–25, 3900–25.

Description of metamorphic rocks.—The sequence is composed of dark carbonaceous (graphitic?) sericitic chloritic metasiltstone and dark carbonaceous (graphitic?) sericite-chlorite slate; quartz-chlorite veinlets are common. The abundance of opaque carbonaceous or graphitic material in streaks, layers, and disseminated "clouds" makes it difficult to assess the degree of metamorphism—probably it is weak. Foliation is expressed by mica and chlorite orientation and streaks of opaque matter, but the shearing element is not as high as in other parts of this zone (Pl. 2).

This well penetrated the black slate belt in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—None.

County.—Bell.

Well name.—Bell County Oil Company No. 1 T. R. Holcomb.

Location.—Louis Walker survey; 3 mi. W of Belton.

Elevation.—760 feet (from topographic map). *Total depth.*—1,640 feet. *Completed.*—1921.

Top of Paleozoic rocks.—1,107 feet. *Elevation of Paleozoic rocks.*— -347 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sellards (1933) reported quartzitic sandstone. Udden (Bur. Econ. Geol. files) described a sample from 1,150 feet as dark, sheared, quartzitic sandstone.

This well probably penetrated the Stanley.

X-ray data.—None.

References.—Sellards (1928, p. 12; 1931b, p. 821; 1933, p. 187).
Bureau of Economic Geology files.

County.—Bell.

Well name.—Bell Williams Oil Company No. 3 John Kolls.

Location.—2¼ mi. NW of Belton, E of No. 1 Kolls, S of No. 1 Hair.

Elevation.—625 feet (from topographic map). *Total depth.*—1,405(?) feet; 1,446(?) feet. *Completed.*—Before 1930.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—According to Adkins and Arick (1930), the well penetrated black shale and quartzite. Bureau of Economic Geology files report total depth 1,405 feet in black limestone. This well probably penetrated the Stanley.

X-ray data.—None.

References.—Adkins and Arick (1930, pp. 16, 86).
Bureau of Economic Geology files.

County.—Bell.

Well name.—Bell Williams Oil Company No. 1 B. F. Warrick.

Location.—E. Ingram survey; 6.7 mi. NW of Jarrell; location is S of J. B. Hartman No. 1 B. F. Warrick.

Elevation.—864 feet (by aneroid barometer). *Total depth.*—2,203 feet. *Completed.*—Before 1925.

Top of Paleozoic rocks.—1,200 feet. *Elevation of Paleozoic rocks.*— -336 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1190–1255 (2), 1304–07, 1336–73, 1372½, 1535, 1660, 1765 (2), 2203 (2).

Description of Paleozoic rocks.—Sellards (1931b, 1933) described the section as "hard shale and quartzitic sandstone." Udden (Bur. Econ. Geol. files) described scattered samples from 1,190 to 1,373 feet as dark to black schistose shale and greenish to dark gray indurated sandstone.

The sequence is composed of dark silty shale and angular, poorly sorted, argillaceous feldspathic quartz sandstone cut by quartz veinlets. The rocks are Ouachita facies and are identified as Stanley; some samples show incipient metamorphism.

X-ray data.—None.

References.—Barnes (1948); Sellards (1931b, p. 821; 1933, p. 135).
Bureau of Economic Geology files.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—Davidson et al. No. 2 Warrick.

Location.—E. Ingram survey; 2,250 feet FNEL, 900 feet FNWL.

Elevation.—ni. *Total depth.*—3,600 feet. *Completed.*—1934.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—See other wells in E. Ingram survey (p. 215).

X-ray data.—None.

References.—None.

County.—Bell.

Well name.—Downs, Perry, and Hughes No. 4 John Kolls.

Location.—2¾ mi. NW of Belton.

Elevation.—625 feet (from topographic map). *Total depth.*—1,405(?) feet; 1,446(?) feet. *Completed.*—1916.

Top of Paleozoic rocks.—1,194 feet. *Elevation of Paleozoic rocks.*— -569 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—According to Adkins and Arick (1930), this well penetrated black shale and quartzite. Description of samples in Bureau of Economic Geology files shows dark limestone in the interval 1,269 to 1,324 feet, dark sandstone and shale at 1,400 feet, and total depth 5 feet into black limestone.

This well probably penetrated the Stanley.

X-ray data.—None.

References.—Adkins and Arick (1930, pp. 16, 86); Sellards (1928, p. 12).
Bureau of Economic Geology files.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—E. A. Dunham No. 1 J. E. Hunt.

Location.—Wm. Brown survey; 900 feet FWL, 330 feet FNL.

Elevation.—809 feet, kelly bushing; 799 feet, ground. *Total depth.*—3,960 feet. *Completed.*—1954.

Top of Paleozoic rocks.—700 feet. *Elevation of Paleozoic rocks.*—+109 feet.

Thin section coverage (depth in feet).—Bureau of Economic Geology: 700–10 (2), 750–60 (2), 760–70 (2), 800–10 (2), 840–50 (2), 999–00 (2), 1100–10, 1200–10, 1300–10, 1400–10, 1600–10, 1700–10, 1800–10, 1900–10, 2000–10, 2100–10, 2200–10, 2300–10, 2400–10, 2500–10, 2600–10, 2700–10, 2790–00 (2), 2900–10 (2), 3000–10 (2), 3100–10 (2), 3200–10 (2), 3300–10 (2), 3370–80 (2).

Description of Paleozoic rocks.—This well penetrated a foreland basin section consisting mostly of dark, micaceous carbonaceous silty and sandy shale (probably Atoka) overlying Marble Falls—Barnett and Ellenburger formations. Sorting is poor in the Atoka sandstones, and sand-silt fractions are angular. The Ellenburger is very fine-grained dolomitic calcilutite and dolomite (grain size dolomite 0.01 to 0.1 mm). The following tops are given by Fowler (1955): top of Paleozoic and Pennsylvanian, 700 feet; top of Marble Falls—Barnett, 2,670 feet; top of Ellenburger, 2,720 feet.

X-ray data.—$I > ML > Ch > K$; $10/7 \sim 1.3$; $F = 20$; $SR = 2.4$. Shales are composed of mixed illite-chlorite and montmorillonite-illite; montmorillonite is characteristic of foreland wells. The amount of montmorillonite decreases at a depth of about 2,600 feet, but small quantities are present to total depth. The upper section of the well resembles Atoka.

References.—Personal communication: P. T. Fowler, Shell Oil Company, 1955.

County.—Bell.

Well name.—Eclipse Oil Company No. 2 Slayden.

Location.—7 mi. S of Killeen.

Elevation.—900 feet (by aneroid barometer). *Total depth.*—1,216 feet. *Completed.*—Before 1921.

Top of Paleozoic rocks.—811 feet. *Elevation of Paleozoic rocks.*—+89 feet.

Thin section coverage (depth in feet).—Bureau of Economic Geology: 811, 850, 940, 945, 950 (5), 1000 (3), 1050 (3).

Description of Paleozoic rocks.—According to Sellards (1931b), novaculite is found at depths of 935 to 1,050 feet and underlies what seems to be Silurian found at depth of 710 to 850 feet; the inversion may be due to overthrusting. Sellards referred to Miser and said that the boundary between Silurian and basal Devonian in the well is in doubt but the sample at 935 feet is the first basal Devonian sample. Samples 940 to 945, 950, 1,000, and 1,050 feet are Devonian; samples from 710 to 850 feet are Silurian.

Sample descriptions in files of the Bureau of Economic Geology report radiolarians in the intervals 850 and 940–945 feet. Samples 850, 935, and 940 feet are described as red, green, and maroon slate, spiculiferous and cut by veins; 945 and 950 feet are spiculitic gray and green chert; 1,000, 1,050, and 1,216 feet are black chert, dolomitic, spiculitic, bituminous, and cut by quartz veins. These last three samples are almost surely Bigfork chert.

Goldstein (1955) reported the following determinations: in Paleozoic (Stanley?) at 811 feet, in Missouri Mountain (?) at 940 feet, in Bigfork at 1,000 feet, last sample (1,050) in Bigfork. He noted that the samples may be mixed.

The sequence is composed mostly of siliceous shale and chert of Ouachita facies containing spines and radiolarian tests. Rocks include dark, micaceous siliceous dolomitic shale containing angular quartz sand and fragments of quartz mosaic, and dark, argillaceous chert rich in organic material. One section marked 950 feet is an angular argillaceous feldspathic quartz sandstone which resembles Stanley; a section marked 1,050 feet is a fine-grained cherty limestone containing a trace of glauconite which suggests Marble Falls lithology. The presence of Marble Falls in this well would indicate an overthrust; the alternative and most likely interpretation is that this rock is a limestone of the Bigfork.

The well penetrated the frontal zone of the Ouachita belt and is west of Shell No. 1 Massie, in which an overthrust was intersected. It is possible, therefore, that deeper drilling in this area will disclose a foreland section beneath an allocthonous Ouachita plate.

X-ray data.—None.

References.—Adkins and Arick (1930, pp. 18–20); Barnes (1948); Sellards (1928, p. 13; 1931b, p. 821; 1933, p. 187).

Bureau of Economic Geology files.

Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Bell.

Well name.—B. F. Gilchrist No. 1 Curb-Fee.

Location.—Trimmer Creek School block, J. E. Evitts survey; 330 feet FNL, 330 feet FWL; 4 mi. S of Killeen.

Elevation.—825 feet. *Total depth.*—2,025 feet. *Completed.*—1949.

Top of Paleozoic rocks.—828(?) feet. *Elevation of Paleozoic rocks.*— -3(?) feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1240–45. PAN AMERICAN PETROLEUM CORPORATION: 1215–20, 1220–25, 1270–75, 1350–55, 1450–55, 1455–60, 1500–05, 1585–90, 1665–75, 1720–25, 1795–1805, 1870–75, 2010–15.

Description of Paleozoic rocks.—The sequence consists of dark chert containing organic material, commonly dolomitic, dark siliceous shale rich in organic material, and fine-grained pyritic siliceous dolomitic limestone, locally spiculitic. The rocks are typical Bigfork. There is no visible metamorphism.

This well is within the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. B. Souther, Pan American Petroleum Corporation, 1956.

County.—Bell.

Well name.—J. B. Hartman No. 1 B. F. Warrick.

Location.—Abner Webb survey; 135 feet FSL, 1,000 feet FEL, 6.8 mi. NW of Jarrell.

Elevation.—944 feet (by aneroid barometer). *Total depth.*—2,807 feet. *Completed.*—1925.

Top of Paleozoic rocks.—973 feet. *Elevation of Paleozoic rocks.*— -29 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1560, 2320 (2), 2440, 2515, 2520.

Description of Paleozoic ricks.—According to Sellards (1931b), two wells on the Warrick ranch in southern Bell County passed through slickensided black somewhat schistose shales and greenish quartzitic sandstone from the base of the Cretaceous at or near 973 feet to 1,373 feet in one well and 2,772 feet in the other, and the section is probably Stanley-Jackfork.

The sequence is composed of angular, poorly to fairly well-sorted, argillaceous feldspathic quartz sandstone containing garnet in the heavy mineral fraction and dark shale; quartz veinlets are common. The rocks are unmetamorphosed Ouachita facies showing typical Stanley lithology; cf. Bell Williams No. 1 Warrick.

This well penetrates the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1928, p. 16; 1931b, p. 826; 1933, p. 188).

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—J. B. Hartman No. 2 B. F. Warrick.

Location.—6.8 mi. NW of Jarrell.

Elevation.—900± feet. *Total depth.*—2,772 feet. *Completed.*—ni.

Top of Paleozoic rocks.—973 feet. *Elevation of Paleozoic rocks.*— -73± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—See No. 1 Warrick, page 217.

X-ray data.—None.

References.—See No. 1 Warrick, page 217.

County.—Bell.

Well name.—A. B. Johnson No. 1 F. C. Howard.

Location.—W. P. Johnston survey; 80 feet FNEL, 1,900 feet FNWL; 2½ mi. S of Moody.

Elevation.—729 feet, derrick floor; 725 feet, ground. *Total depth.*—2,264 feet. *Completed.*—1951.

Top of Paleozoic rocks.—1,415 feet. *Elevation of Paleozoic rocks.*— -686 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1420–30, 1470–80, 1550–60, 1900–10, 2200–10.

Description of Paleozoic rocks.—The sequence in this well is composed of fine-grained, mostly angular, poorly sorted, argillaceous micaceous feldspathic quartz sandstone and dark shale; angular garnet is present in the sandstones in some intervals. The rocks are veined with calcite. The lithology is Stanley.

This well penetrated unmetamorphosed Stanley shale in the frontal zone of the Ouachita belt.

X-ray data.—I > Ch > ML > K; 10/7 ∼ 1; F = 20; SR = 1.8.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957.

County.—Bell.

Well name.—Mellon Oil Company No. 1 Noah Bailey.

Location.—James Evitts survey; 7 mi. S, 4 mi. E of Killeen.

Elevation.—700 feet (by aneroid barometer). *Total depth.*—3,790 feet. *Completed.*—Before 1928.

Top of Paleozoic rocks.—798 feet. *Elevation of Paleozoic rocks.*— -98 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 860, 1761–1822, 1920, 2640–55, 2655–75 (2), 2740, 2890–2915, 3015–22, 3350–60, 3540–50, 3645–55, 3678–82, 3770–73. BUREAU OF ECONOMIC GEOLOGY: 1920, 3370–80, 3380–85 (5), 3390–00, 3470–75, 3475–80, 3480–85, 3485–00 (2), 3500–05 (2), 3505–10, 3540–45 (6), 3540–50 (2), 3550–60 (2), 3560–70 (2), 3570–80, 3575–80 (2), 3590–05 (4), 3605–15 (4), 3615–25 (2), 3625–40 (2), 3640–45 (2), 3640–50 (4), 3645–50 (2), 3650–55 (2), 3655–60 (2), 3660–72, 3690–95, 3695–00, 3720–25, 3728–32, 3735–40, 3750–55, 3770–73, 3785–90.

Description of Paleozoic rocks.—Sellards (1931b), referring to Miser, reported that this well entered black shales at 860 feet, and that these shales are probably Stanley. At 2,500 feet the well encountered novaculite of probable Devonian age. Stanley was encountered again between 2,930 and 3,160 feet due to complicated folding. The well terminated in novaculite. Miser was quoted as follows: "Samples from this well from depth 2,500–3,800 are chiefly and possibly entirely novaculite although it is possible that due to complicated folding the Stanley shale may come into the section at approximately 2,930 to 3,160 feet. The samples immediately under the Cretaceous in this well at 860 and at about 1,900 are regarded as Stanley. The brown shale at 2,640 to 2,655 is not exceptional for the Devonian since brown shales are found occasionally in the upper part of the novaculite. Fossils were found from 3,640–3,650." Sample descriptions in the files of the Bureau of Economic Geology report that radiolarians were found in the intervals 2,640–2,670, 2,730–2,740, 2,750–2,760, 2,850–2,860, 3,310–3,400, 3,490–3,500, 3,520–3,540, and 3,640–3,650 feet.

Goldstein (1955) reported first sample in Paleozoic (Stanley) at 860 feet, base of Stanley at 2,640 feet, top of Bigfork at 3,500(?) feet, total depth 3,790 feet in Bigfork.

The sequence is composed of angular to subangular, poorly sorted, chloritic and micaeous feldspathic quartz sandstone, dark shale, and metashale overlying a dominantly siliceous section. In the upper part, the siliceous section is composed of light and dark cherts, commonly argillaceous, micaceous, and dolomitic and/or sideritic, and dark sandy chloritic and micaceous metashale; the cherts are fractured and cut by quartz veinlets. The main part of the siliceous section is composed of greenish, pyritiferous argillaceous dolomitic and/or sideritic chert and siliceous shale with lesser amounts of dark, red and brown silty shale; these rocks are veined with quartz, quartz-chlorite, and chlorite and contain radiolarians, spores, and dark organic material. Toward the bottom of the sequence the cherts are darker and contain more organic material. The section is Ouachita facies and the shales show local incipient to very weak metamorphism. The upper greenish cherts are similar to the Arkansas novaculite, but the dark cherts toward the bottom are more typically Bigfork; the sandstone and shale at the top of the Paleozoic sequence are Stanley.

This well penetrated the frontal zone of the Ouachita belt in a structurally complex area. Shell No. 1 Massie, about 2 miles to the southeast, intersected a thrust beneath Ouachita facies rocks and bottomed in foreland rocks; deeper drilling in the area of Mellon No. 1 Bailey might encounter foreland rocks.

X-ray data.—None.

References.—Adkins and Arick (1930, pp. 18–20, 86); Barnes (*in* Sellards, 1933, pp. 134–135; 1948); Goldstein and Reno (1952, p. 2285); Sellards (1928, pp. 4–11; 1931b, p. 821; 1933, p. 135).
Bureau of Economic Geology files.
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—Nolan Bell Oil Company No. 1 William Bacon.

Location.—Vincent Evans survey; 3.9 mi. W of Nolanville, 6.4 mi. E of Killeen, 0.6 mi. S of public road.

Elevation.—820 feet (by aneroid barometer). *Total depth.*—2,962 feet. *Completed.*—1928.

Top of Paleozoic rocks.—905± feet. *Elevation of Paleozoic rocks.*— -85± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1100–10.

Description of Paleozoic rocks.—Sellards (1928) described the Paleozoic section as black slaty shale. The single section examined is a very dark, slightly calcareous siliceous(?) shale. There are no indications of metamorphism. The well penetrated the frontal zone of the Ouachita belt; more information is available on a companion well, the No. 2 Bacon.

X-ray data.—None.

References.—Adkins and Arick (1930, pp. 13, 86); Sellards (1928, pp. 2–3).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—Nolan Bell Oil Company No. 2 William Bacon.

Location.—Vincent Evans survey; 3.9 mi. W. of Nolanville, 6.4 mi. E. of Killeen, 0.6 mi. S of public road.

Elevation.—820 feet (by aneroid barometer). *Total depth.*—1,820 feet. *Completed.*—1928.

Top of Paleozoic rocks.—896 feet. *Elevation of Paleozoic rocks.*— -76 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1805–15, 1815–20. BUREAU OF ECONOMIC GEOLOGY: 1820.

Description of Paleozoic and igneous rocks.—According to Sellards (1931b), the Bacon well in Bell County [whether this was the No. 1 Bacon or the No. 2 Bacon was not specified] entered a black shale which contains graptolites; these were identified by E. O. Ulrich as probably Ordovician but possibly ranging as high as the base of the Silurian. Adkins and Arick (1930, p. 13) described the sequence in the No. 2 Bacon as indurated black shale overlying a dark greenish crystalline rock; there was some discussion as to whether a sample at 1,100 feet might be Ellenburger, with the weight of opinion in the negative. A complete sample description by H. T. Kniker and E. B. Stiles was given in Sellards (1928, p. 3) in which it was suggested that the crystalline rock might be pre-Paleozoic with the overlying rocks Ellenburger and Barnett.

All of the thin sections examined for this study (see above) were altered igneous rock—fine-grained olivine gabbro and augite-biotite microsyenite; undoubtedly, this is the dark greenish crystalline rock referred to in the sample descriptions.

Wells immediately to the south of the Bacon wells (Gilchrist No. 1 Curb-Fee, Mellon No. 1 Bailey) penetrated Ouachita facies Ordovician rocks; the presence of the Ordovician graptolites noted by Sellards (1931b) therefore indicates that the black shales in the Bacon wells are Ouachita facies Ordovician rocks. The igneous rock in the No. 2 is probably a younger intrusion rather than Precambrian basement. The presence of olivine gabbro suggests a relationship to the Cretaceous-Tertiary basic intrusives of the Balcones fault zone, the nearest of which occur to the south in Williamson and Travis counties (p. 111); deep wells in the Ouachita belt to the north in Coryell County and to the southeast in Bell County were in sedimentary rocks at total depth of 9,275 and 7,927 feet (No. 1

Day and No. 1 Massie, respectively) and make it very unlikely that Precambrian basement rocks were encountered at such a shallow depth as 1,800 feet.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Adkins and Arick (1930, pp. 13, 86); Barnes (1948); Sellards (1928, pp. 3–4; 1931b, p. 827; 1933, p. 187).

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—Petoskey Oil Company No. 1 John Kolls.

Location.—2½ mi. NW of Belton.

Elevation.—625 feet (from topographic map). *Total depth.*—ni. *Completed.*—Before 1930.

In Paleozoic rocks.—1,170 feet. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1800±.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology for the intervals 1,170, 1,187, 1,190, 1,193, 1,197, and 1,198 feet show that the sequence is composed of dark gray shale and sandstone.

The single sample examined in this study is dark red, hematitic metashale, locally brecciated and extensively veined with quartz; metamorphism is incipient.

This well probably penetrated the frontal zone of the Ouachita belt; the rocks appear to be incipiently metamorphosed Stanley, but the sample is insufficient for a positive identification.

X-ray data.—None.

References.—Adkins and Arick (1930, p. 86).

Bureau of Economic Geology files.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—Rio Grande Oil Company No. 1. D. W. Hair.

Location.—Lewis Walker survey; 2¼ mi. NE of Belton.

Elevation.—625 feet (from topographic map). *Total depth.*—2,002 feet. *Completed.*—1929.

Top of Paleozoic rocks.—1,157± feet. *Elevation of Paleozoic rocks.*— −532± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1305–1310, 1305+.

Description of Paleozoic rocks.—Sellards (1931b) described the sequence as black shale and gray quartzitic sandstone.

Thin section examination shows fine- to medium-grained, angular, very poorly sorted, slightly argillaceous micaceous feldspathic quartz sandstone veined by quartz-bitumen and containing angular garnet in the heavy mineral fraction; the lithology is Stanley. There are indications of incipient metamorphism.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Adkins and Arick (1930, pp. 17, 86); Barnes (1948); Sellards (1931b, p. 821; 1933, p. 187).

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—Shambeck and Casey No. 1 Sudie Baugh.

Location.—E&F survey, Arocha grant; 8 mi. E. of Temple.

Elevation.—590 feet, derrick floor; 584 feet, ground. *Total depth.*—4,473 feet. *Completed.*—1953.

Top of Paleozoic rocks.—3,360 feet. *Elevation of Paleozoic rocks.*— −2,770 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4000–10, 4010–20, 4090–4100, 4190–4200, 4240–50 (2), 4340–70 (2), 4410–20, 4450–60.

Description of Paleozoic rocks.—Top of Paleozoic and Pennsylvanian rocks was established at 3,360 feet according to operator (Fowler, 1955).

This sequence is composed of (1) dark, fine-grained, angular, poorly sorted, dolomitic carbonaceous chloritic micaceous feldspathic quartz sandstone containing abundant rock fragments (slate, chert, quartz mosaic); (2) dark, fine-grained, angular, dolomitic carbonaceous chloritic micaceous feldspathic quartz siltstone; (3) dark, micaceous chloritic silty metashale; (4) in the 4,340 to 4,370-foot interval—light-colored, microgranular to cryptocrystalline chert (Arkansas novaculite type) containing a few relict radiolarian tests and spicules, and in the 4,410 to 4,420-foot interval—dark, fine-grained dolomite. The dark, fine-grained dolomitic clastic sequence is similar to the section encountered in other wells in this area, but the presence of Arkansas novaculite fragments is difficult to explain; one possible answer is that the sequence of fine, dark clastics is a near-source facies of the chert sequence and that thin chert beds persist in this eastern area (p. 78).

Degree of metamorphism is difficult to assess in these rocks because of the obscuring effect of the carbonaceous debris, but it appears to be lower than in other rocks in this part of the frontal zone; metamorphism is estimated as incipient(?).

This well penetrated incipiently metamorphosed dark clastic Ouachita facies rocks in the interior part of the frontal zone of the belt.

X-ray data.—I > Ch; 10/7 ~ 1; F = 20; SR = 3.8.

References.—Personal communication: P. T. Fowler, Shell Oil Company, 1955.

County.—Bell.

Well name.—Shell Oil Company No. 1 C. E. Massie.

Location.—Wm. Leftwich survey; 12 mi. SW of Belton.

Elevation.—624 feet. *Total depth.*—7,927 feet. *Completed.*—1956.

Top of Paleozoic rocks.—720 feet. *Elevation of Paleozoic rocks.*— -96 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 790–00, 850–60 (2), 920–30 (2), 1780–90 (2), 2480–90 (2), 3000–10 (2), 4210–20 (2), 4270–80 (3), 4760–70 (3), 5060–70 (2), 6130–40 (2), 6650–60 (2), 7130–40 (2).

Description of Paleozoic rocks.—Because of apparent structural complexity the following identifications are tentative. They are based on Shell Oil Company descriptions and identifications modified by Bureau of Economic Geology sample descriptions and thin section studies: Stanley, 720 to 4,700± feet; Arkansas novaculite, 4,700± to 4,800± feet; probable fault, 4,800± feet; probable Womble (possibly including Bigfork), 4,800± to 5,050 feet; major tectonic break, probably an overthrust, 5,050 feet; Atoka-type Pennsylvanian, 5,050 to 6,350 feet; mixed lithologic types including Marble Falls, Barnett-Chappel, and Ellenburger, 6,350 to 6,700 feet; Ellenburger, 6,700 to 7,927 feet total depth.

The Stanley in this well is composed of fine-grained, angular, poorly sorted, feldspathic quartz sandstone, locally argillaceous, and containing a high percentage of garnet in the heavy mineral fraction, and dark silty shale and metashale, locally containing carbonaceous debris; quartz, quartz-bitumen and quartz-calcite veinlets are common. The shales are commonly contorted. The interval 4,760 to 4,770 feet contains green cryptocrystalline chert; some fragments are argillaceous and some contain elliptical carbonate bodies. The chert is cut by quartz and quartz-chlorite veinlets, and some of the quartz veinlets have bituminous centers. This green chert is identified as Arkansas novaculite. Dark, micaceous metashale beneath the green chert is tentatively considered to be Womble. Atoka beds are fine-grained, angular to subround, poorly sorted, argillaceous calcareous feldspathic quartz sandstone and dark, silty shale. The interval 6,130 to 6,140 feet in the mixed section is comprised of fossiliferous dolomitic calcilutite and dark spiculitic dolomitic argillaceous chert rich in organic material (possibly Marble Falls). The Ellenburger section is composed of fine granular dolomite, dolomitic calcilutite, and calcareous dolomite.

This well penetrated the frontal zone of the Ouachita belt, intersected an overthrust, and bottomed in foreland Ellenburger dolomite. The shales in the allochthonous Ouachita plate show incipient metamorphism. Shell No. 1 Massie demonstrates that deep drilling in the area of its location will encounter foreland rocks.

X-ray data.—Arkansas novaculite, Womble, and Atoka all have relatively similar clay suites: I > Ch > ML; 10/7 ~ 1; SR = 1.6 (Atoka). Ellenburger and Chappel are similar: I > ML > Ch; 10/7 ~ 8; SR = 1.0.

References.—Personal communication: R. P. Maner and E. J. Theessen, Shell Oil Company, 1956. Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—U. S. Army No. 1 McCloskey Hospital Water Well.

Location.—McCloskey Hospital.

Elevation.—678 feet. *Total depth.*—2,323 feet. *Completed.*—1944.

Top of Paleozoic rocks.—2,318 feet. *Elevation of Paleozoic rocks.*— -1,640 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2319±.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology report hard, tough, gray, laminated, metamorphosed shale cut by quartz veins.

The single sample examined in this study is dark silty hematitic chlorite-sericite metashale or clay-slate veined with quartz and calcite; locally the rock is brecciated. Metamorphism is very weak.

The well penetrated very weakly metamorphosed dark clastic Ouachita facies rocks in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.
Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Well name.—J. E. Winans & Forbes No. 1 Ferguson.

Location.—James Bowers survey; 7 mi. NW of Belton.

Elevation.—550 feet (from topographic map). *Total depth.*—1,780 feet. *Completed.*—1929.

Top of Paleozoic rocks.—821± feet. *Elevation of Paleozoic rocks.*— -271± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1294, 1320, 1367, 1406, 1512, 1745.

Description of Paleozoic rocks.—Sellards (1931b) reported that cores at intervals from 1,200 to 1,700 feet are prevailingly of noncalcareous black shales and quartzitic sandstones; the rock is cut by calcite veins and the shale shows slickensiding. He concluded that the sequence is Stanley-Jackfork.

Thin sections show that the sequence is composed of dark silty shale and fine-grained, angular, poorly sorted, argillaceous and chloritic feldspathic quartz sandstone veined with quartz-calcite and containing abundant angular garnet in the heavy mineral fraction. The rocks are Stanley. Some of the samples show incipient metamorphism.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Adkins and Arick (1930, p. 86); Barnes (1948); Sellards (1931b, p. 821; 1933, p. 187).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bell.

Additional wells not shown on map (Pl. 2) and not studied because of lack of samples or basic data:

W. S. STANFIELD NO. 2 LUDWICK—
Location: 1 mi. NNE of Bland. *Elevation:* 600 feet (topographic map). *Total depth:* 1,510 feet. *Completed:* 1924(?). *Top of Paleozoic rocks:* 1,200 feet.

KILLEEN-BELL OIL COMPANY NO. 1 SWOPE—
Location: (?). *Elevation:* 888 feet (aneroid barometer). *Top of Paleozoic rocks:* 850 feet or higher. "Pyritic micaceous gray sandstone on dump."

U. S. ARMY NO. 2 WILSON—
Location: NW of Belton. *Elevation:* 532 feet. *Total depth:* 964 feet. *Completed:* 1942. *Top of Paleozoic rocks:* 945 feet. "Red, brown and green shales and micaceous schist."

U. S. ARMY NO. 1 BLOOMER—
Location: 3 mi. NW of Belton. *Elevation:* 533.5 feet. *Total depth:* 999 feet. *Top of Paleozoic rocks:* 982 feet. "Red, brown and green clays and sandy shales."

U. S. ARMY NO. 1 ODELL—
Elevation: 603.4 feet. *Completed:* 1941.

U. S. ARMY NO. 1 SAFELY—
Elevation: 547.7 feet. *Total depth:* 932 feet. *Top of Paleozoic rocks:* 925 feet. "Dark blue, brown and red shales."

U. S. ARMY NO. 1 JARRELL—
Location: 3½ mi. SW of Belton. *Total depth:* 956 feet. *Top of Paleozoic rocks:* 939 feet.

C. J. FOSTER DRILLING COMPANY NO. 1 G. W. TYLER EST.—
Location: O. T. Tyler survey; 3,045 feet FNWL, 1,150 feet FNEL (Leon River), ¾ mi. E of Belton. *Elevation:* 513 feet. *Total depth:* 1,720 feet. *Completed:* 1953.

LAYNE-TEXAS NO. 3 CITY OF TEMPLE—
Elevation: 528(?) feet. *Total depth:* 1,259 feet. *Completed:* 1951.

MEYERS & SONS NO. 1 BRAZOS RIVER ELECTRIC—
Total depth: 1,358 feet. *Completed:* 1948.

MEYERS & SONS NO. 1 SANDERFORD—

Total depth: 822 feet. Single sample in Bureau of Economic Geology Well Sample Library (797 to 822 feet) is fine-grained, angular, poorly to fairly well-sorted, chloritic feldspathic quartz sandstone, probably Stanley.

County.—Bexar.

Well name.—Anderson-Prichard Oil Corporation No. 1 E. H. Yturri.

Location.—Adam Stafford survey; 10 mi. SE of San Antonio.

Elevation.—598 feet. *Total depth.*—4,301 feet. *Completed.*—1948.

Top of metamorphic rocks.—4,260 feet. *Elevation of metamorphic rocks.*— -3,662 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 4298. BUREAU OF ECONOMIC GEOLOGY: 4268, 4276.

Description of metamorphic rocks.—The sequence is composed of fine-grained sericitic dolomitic metaquartzite and chloritic sericite phyllite; locally the rock is a quartzose dolomite marble. Some of the fragments contain opaque graphitic(?) material and some are cut by quartz and dolomite veinlets. One phyllite fragment contains abundant fine rutile needles. Metamorphism is low grade with a high shearing component; foliation is expressed in sheared micas and stretched grains.

This well penetrated the interior zone of the Ouachita structural belt.

X-ray data.—I > Ch > ML; 10/7 ~ 1.

References.—Personal communication: P. T. Fowler, Shell Oil Company, 1955; August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bexar.

Well name.—Arkansas Fuel Oil Company No. 1 George Burkhardt.

Location.—Alfonso Steele survey; from N cor. of Manjaros survey SSE 3,000 feet along its NEL, thence 330 feet ENE to location; 7 mi. NE of Elmendorf.

Elevation.—563 feet. *Total depth.*—5,097 feet. *Completed.*—1947.

Top of metamorphic rocks.—5,060 feet. *Elevation of metamorphic rocks.*— -4,497 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 5000–15, 5045–60, 5090–95, 5095–98.

Description of metamorphic rocks.—The sequence is made up of sericitic metaquartzite and sericite chlorite phyllite; the metaquartzite is composed of large unreduced augen of quartz in a matrix of finer crushed and granulated quartz containing scattered rhombs and cross-cutting veinlets of dolomite. One fragment of phyllite contains garnet. Except for the presence of garnet, metamorphism appears to be low grade with a high shearing component; structures are foliation with grain stretching and deformation. There are two possible explanations for the presence of garnet in these rocks: (1) The rocks were at one time of higher metamorphic grade and were subjected to retrograde metamorphism during extreme shearing; muscovite and possibly potassium feldspar were converted to sericite. In such retrograde reactions, however, garnet commonly is converted to chlorite and there is no evidence that the garnet has undergone retrogressive metamorphism. (2) The garnet in these rocks may be a manganese garnet stable at lower temperatures than the common almandine garnet of regionally metamorphosed terranes.

This well penetrated the interior zone of the Ouachita structural belt.

X-ray data.—I > Ch; 10/7 ~ 1; (poor pattern).

References.—Personal communication: J. K. Rogers, Arkansas Fuel Oil Company, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bexar.

Well name.—Bur-Kan Petroleum Company and Stanolind Oil and Gas Company No. 1 Lee Hubbard.

Location.—Block 75, Ignacio Tejada grant (Wm. Miller survey); 660 feet FSL, 660 feet FEL of Lot 7; 2 mi. E of Lytle.

Elevation.—735 feet, derrick floor; 725 feet, ground. *Total depth.*—5,203 feet. *Completed.*—1948.

Top of metamorphic rocks.—4,940 feet. *Elevation of metamorphic rocks.*— -4,205 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4960–70, 5040–50, 5100–10, 5150–60, 5190–00.

Description of metamorphic rocks.—The sequence is composed of pyritic calcareous sericite-chlorite-epidote phyllite and amphibole-epidote phyllite or very fine-grained schist. The rock is veined by massive calcite. Crumpling, wrinkling, contortion, and grain stretching are common. The general plane of the foliation dips about 45 degrees in a core. Metamorphism is low grade with a high shearing element.

The well penetrated the interior zone of the Ouachita structural belt.

X-ray data.—Ch; F = 20 (ML from caved material?); amphibole.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; J. B. Souther, Pan American Petroleum Corporation, 1955, 1956.

County.—Bexar.

Well name.—Fair and Woodward No. 1 Pauline Lyro.

Location.—J. M. Bustillos survey; 660 feet FSEL, 660 feet FNEL; 1 mi. N of St. Hedwig.

Elevation.—602 feet, derrick floor; 592 feet, ground. *Total depth.*—4,607 feet. *Completed.*—1946.

Top of metamorphic rocks.—4,433 feet. *Elevation of metamorphic rocks.*— -3,831 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4466–77, 4488–4501, 4501–13, 4535–46.

Description of metamorphic rocks.—The sequence is composed of chlorite-sericite phyllite and chloritic sericitic metaquartzite; the rocks are cut by both pre-shearing and post-shearing quartz veinlets. Locally, the foliation is thrown into microfolds. Metamorphism is low grade with a high shearing element.

This well penetrated the interior zone of the Ouachita structural belt.

X-ray data.—None.

References.—Personal communication: P. T. Fowler, Shell Oil Company, 1955; August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bexar.

Well name.—Gas Ridge Syndicate (Clark Oil Company) No. 1 Pepper.

Location.—BBB&C survey; 200 FEL, 1,200 feet FSL; 14 mi. W of San Antonio.

Elevation.—935 feet. *Total depth.*—3,783 feet. *Completed.*—1921.

Top of Paleozoic rocks.—2,845 feet. *Elevation of Paleozoic rocks.*— -1,910 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1963–68, 1987–98, 2579–82, 2903–09, 2905–09, 2985–91, 3308, 3402–14, 3475–80, 3480–90, 3540–57 (2), 3568–80, 3629 (3), 3676–80 (2), 3702, 3748, 3770–76.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology show a sequence of indurated, black, slightly micaceous sandy shale, locally slickensided, with gray sandstone abundant toward the bottom; fragments of white calcite and milky quartz vein material are present.

The sequence is composed of unmetamorphosed, fine-grained, angular, poorly sorted, argillaceous chloritic micaceous feldspathic quartz sandstone and arkose, commonly dolomitic, argillaceous micaceous siltstone, and dark, silty shale. Carbonaceous material is common in the shales. The rocks contain abundant veinlets of quartz, quartz-dolomite, and quartz-chlorite, and massively veined rocks show incipient metamorphism. Sellards (1931b) identified this section as probably Stanley-Jackfork.

This well penetrated the southern part of the frontal zone of the Ouachita belt; the extensive veining and high percentage of quartz sand of probable metamorphic origin (stretched quartz mosaic fragments; abundant composite grains and grains with undulose extinction) and of vein origin indicate the proximity of a metamorphic terrane which could only be to the south. The rocks are probably upper Paleozoic Ouachita facies.

X-ray data.—None.

References.—Sellards (1931b, p. 822; 1933, p. 188).

Personal communication: P. T. Fowler, Shell Oil Company, 1955; August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Bureau of Economic Geology files.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bexar.

Well name.—General Crude Oil Company No. 1 Rogers Ranch.

Location.—J. S. Collard survey; 1,100 feet FWL, 1,950 feet FNL; 8 mi. W of San Antonio.

Elevation.—812 feet, derrick floor; 801 feet, ground. *Total depth.*—5,896 feet. *Completed.*—1954.

Top of metamorphic rocks.—2,560 feet. *Elevation of metamorphic rocks.*— -1,748 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2673, 2676, 3055–60, 3160, 3161, 3170 (2), 3267–68, 4081, 5713, 5894 (2), 5895. SHELL OIL COMPANY: 5713–23 (3), 5893–96.

Description of metamorphic rocks.—The upper part of the sequence, through the 5,713–5,723-foot interval, is composed of dark carbonaceous (graphitic?) sericitic and chloritic slate and dark, slaty, carbonaceous sericitic chloritic feldspathic metasiltstone; quartz and carbonate veins are abundant. The following structures were observed: bedding, incipient foliation, microfolding and microfaulting, parallel shear planes, contortion, and convolution. In the 5,713-foot interval the slate includes large augen of brecciated chlorite-biotite-albite granodiorite, locally sericitized; their inclusion in the slate combined with the other structures indicates extreme shearing, probably associated with overthrusting (Pl. 2). The slate sequence in general shows weak regional metamorphism with extreme shear and extensive soaking by vein-forming solutions; in many samples the widespread hydrothermal effects make it difficult to assess regional metamorphism.

The slate sequence lies on almost completely sericitized and chloritized andesite. This rock consists of relict plagioclase laths in various stages of sericitization in a mass of chlorite speckled with sphene-leucoxene and extensively invaded by quartz. It is not known whether the slate sequence is in fault contact, depositional contact, or intrusive contact with the igneous section.

This well penetrated highly sheared rocks of the black slate belt in the interior zone of the Ouachita structural belt immediately south of the Luling overthrust front.

X-ray data.—$I > Ch$; $10/7 \sim 1.3$; $F = 20$; $SR = 3.8$.

References.—Personal communication: J. B. Souther, Pan American Petroleum Corporation, 1955. Cores are in Bureau of Economic Geology Well Sample Library.

County.—Bexar.

Well name.—General Crude Oil Company No. 1 J. H. Talley.

Location.—T. R. Edmondson survey; 14 mi. W of San Antonio.

Elevation.—881 feet. *Total depth.*—2,622 feet. *Completed.*—1954.

Top of Paleozoic rocks.—2,600 feet. *Elevation of Paleozoic rocks.*— -1,719 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2615–22 (2).

Description of Paleozoic rocks.—The single sample examined in this study is fine-grained, angular, poorly sorted, argillaceous micaceous feldspathic quartz sandstone veined by quartz and carbonate; the rock is probably upper Paleozoic Ouachita facies; there is no metamorphism.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. B. Souther, Pan American Petroleum Corporation, 1955. A core is in the Bureau of Economic Geology Well Sample Library.

County.—Bexar.

Well name.—Hickok & Reynolds No. 1 Ewert.

Location.—Thomas York survey; 6,750 feet E of EL of Sarah Taylor survey, 1,150 feet SW of SWL of BBB&C survey; 15 mi. NW of San Antonio.

Elevation.—995 feet. *Total depth.*—3,004 feet. *Completed.*—1938.

Top of Paleozoic rocks.—2,630 feet. *Elevation of Paleozoic rocks.*— -1,635 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2640–50, 2650–2704, 2715–30, 2820–30, 2969–73. SHELL OIL COMPANY: 2640–50.

Description of Paleozoic rocks.—Sample log (P. S. Morey, Bureau of Economic Geology) shows top of Pennsylvanian at 2,640 feet in dark gray to black shaly sandstone. Sample descriptions in Bureau of Economic Geology files report the interval 2,630 to 3,014 feet total depth as sandstone. Thin section examination shows that the sequence is composed of fine-grained, angular, poorly sorted, argillaceous micaceous feldspathic quartz sandstone cut by quartz veinlets; the rocks are probably upper Paleozoic Ouachita facies. Locally, the presence of new chlorite suggests incipient metamorphism.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bexar.

Well name.—Mid-Tex Production Company No. 1 C. G. Walker.

Location.—S. N. Dobie survey; 3,100 feet FNEL, 3,300 feet FNWL; 10 mi. N of San Antonio.

Elevation.—840 feet, derrick floor. *Total depth.*—2,132 feet. *Completed.*—1935.

Top of Paleozoic rocks.—2,110(?) feet. *Elevation of Paleozoic rocks.*— -1,270(?) feet.

Thin section coverage (depth in feet.)—SHELL OIL COMPANY: 2118–24.

Description of Paleozoic rocks.—Descriptions of samples in the Bureau of Economic Geology files show very black shale or slate with some quartz in the interval 2,116 to 2,132 feet.

The single section examined in this study is fine-grained, angular, poorly sorted, micaceous feldspathic quartz sandstone cut by quartz-calcite veinlets; rocks are upper Paleozoic Ouachita facies with incipient metamorphism.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bexar.

Well name.—H. A. Pagenkopf No. 1 Max Blum.

Location.—Maria F. Rodriguez survey; 400 feet FWL, 4,800 feet FNL; 10 mi. SW of San Antonio.

Elevation.—714 feet. *Total depth.*—7,179 feet. *Completed.*—1946.

Top of Paleozoic rocks.—4,580 feet. *Elevation of Paleozoic rocks.*— -3,866 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4760–75, 4775–90, 5095–5110, 5643–50, 6090–6108, 6123–38, 6648–69, 6745–64, 7085–7113.

Description of Paleozoic rocks.—According to Goldstein (1955), the base of Cretaceous gravels and top of Jurassic(?) is 3,900(?) feet with total depth at 7,197 feet in Jurassic(?). Morgan (1952) remarked that this well passed from Comanche rocks at 4,500 feet into red and gray shale with thin sandstone and limestone beds to a total depth of 7,179 feet; he believed that the pre-Cretaceous section is Permo-Pennsylvanian on the basis of similarity to the section in Magnolia No. 1 McKinley in Frio County. The age of the lower unmetamorphosed clastic section in this well is still being argued, but general stratigraphy and study of plant remains seem to support a Permo-Pennsylvanian age over a Jurassic age.

This well is anomalous in that it penetrates an unmetamorphosed section of Paleozoic rocks (presuming the Permo-Pennsylvanian age is correct) in an area where other wells have encountered highly sheared and altered pre-Cretaceous rocks, mostly phyllites. The rocks are brown, red, and gray micaceous silty shale and fine-grained, angular, poorly sorted, micaceous calcareous sandstone; carbonaceous trash and plant fragments are present. Some fern and Lepidodendron fragments from the 6,734 to 6,737-foot interval were identified as Pennsylvanian.[35] The most reasonable explanation is that this well penetrated Paleozoic (probably post-Atokan) *post-orogenic* sedimentary rocks preserved in a downfaulted block within the deformed and metamorphosed terrane (p. 125).

X-ray data.—None.

References.—H. J. Morgan (1952).

Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; C. A. Stewart, Union Producing Company, 1956.

Sample log by P. S. Morey, Bureau of Economic Geology.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Bexar.

Well name.—Reenlee Oil Corporation No. 1 A. Theis.

Location.—L. Kneipp survey; 660 feet FNWL, 6,625 feet FNEL; 3 mi. S of Wetmore.

Elevation.—806 feet, derrick floor. *Total depth.*—2,105 feet. *Completed.*—1955.

Top of Paleozoic or metamorphic rocks.—2,060 feet. *Elevation of Paleozoic or metamorphic rocks.*— -1,254 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic or metamorphic rocks.—ni.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957; J. R. Sandidge, Magnolia Petroleum Company, 1957.

Samples from upper part of well are in Bureau of Economic Geology Well Sample Library.

[35] Identification by R. W. Brown of the U.S. Geological Survey on core fragments submitted by John R. Sandidge of the Magnolia Petroleum Company.

County.—Bexar.

Well name.—Security Drilling Company No. 2 Englemann.

Location.—Juan Vasquez survey; 660 feet F most E'ly NWL, 330 feet FNEL; 1 mi. SW Selma.

Elevation.—838 feet, derrick floor. *Total depth.*—2,581(?) feet; 2,682(?) feet. *Completed.*—1955.

Top of metamorphic rocks.—2,480 feet. *Elevation of metamorphic rocks.*— -1,642 feet.

Thin section coverage (depth in feet).—None.

Description of metamorphic rocks.—ni.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957; J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Bexar.

Well name.—Union Producing Company No. 1 L. S. McKean.

Location.—Fernando Rodriguez survey; 4,500 feet F most W'ly EL, 3,300 feet F most N'ly NWL.

Elevation.—605 feet, derrick floor; 595 feet, ground. *Total depth.*—4,426 feet. *Completed.*—1949.

Top of metamorphic rocks.—4,370 feet. *Elevation of metamorphic rocks.*— -3,765 feet.

Thin section coverage (depth in feet)—None.

Description of metamorphic rocks.—ni.

X-day data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957; C. A. Stewart, Union Producing Company, 1957.

County.—Bexar.

Well name.—U. S. Government No. 1 Camp Bullis Water Well.

Location.—Camp Bullis Military Reservation, 14 mi. NNW of San Antonio, 5 mi. S of Leon Springs, on old Gerter Estate.

Elevation.—1,050 feet (from topographic map). *Total depth.*—1,910 feet. *Completed.*—Before 1919.

Top of Paleozoic rocks.—1,770 feet. *Elevation of Paleozoic rocks.*— -720 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—J. A. Udden (Bur. Econ. Geol. files) described these samples as red, purple, green, dark gray schist, locally black graphitic schist, and vein quartz.

In an early report, Sellards (1919) quoted Udden's determination that this well encountered dark gray graphitic schist; in a later report, however, he described the pre-Comanche sequence as "altered shale" (Sellards, 1931b). No samples were located, but from descriptions of the rocks, it is probable that the Camp Bullis well penetrated dark carbonaceous shale or metashale, possibly slickensided, veined with quartz. The age of the shale is unknown. From the location of the well (Pl. 2), the rocks could be either upper or lower Paleozoic Ouachita facies.

X-ray data.—None.

References.—Sellards (1919, pp. 131–135; 1931b, p. 821.
Bureau of Economic Geology files.

County.—Bexar.

Well name.—U. S. Government No. 1 Leon Springs Water Well.

Location.—Camp Stanley Rifle Range, Leon Springs Military Reservation; 2 mi. NE of Leon Springs.

Elevation.—1,156 feet (from topographic map). *Total depth.*—2,500 feet. *Completed.*—1909.

Top of Paleozoic rocks.—1,046 feet. *Elevation of Paleozoic rocks.*— +110 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—In an early report, Sellards (1919) quoted a description by Alexander Deussen classifying the pre-Comanche rocks as "slate seamed with quartz." In a later report Sellards (1931b) described these rocks as "altered shale." Udden (1919) described them as dove-gray to black slaty material seamed with thin straight quartz veins. Descriptions by Udden in the Bureau of Economic Geology files, dated 1916, show a sequence composed of hard, gray to black fine-textured schist-like slickensided shale veined with quartz, locally micaceous, and with cleavage at an angle to the bedding; in two intervals, one 1,750 feet, one unmarked, Udden described extreme deformation by irregular shearing with quartz veins complexly folded and faulted. In the Cretaceous conglomerate overlying this sequence (1,010 to 1,015-foot interval) he noted the presence of fragments of flint, greenish sandstone, vein quartz, agate, micaceous shale or schist, marble, quartzite, limestone, and slate.

From available descriptions, it would appear that the rocks are dark hard carbonaceous Pennsylvanian shale or metashale veined with quartz. From the location of the well (Pl. 2), the rocks could be either upper or lower Paleozoic Ouachita facies.

X-ray data.—None.

References.—Sellards (1919, pp. 129–131; 1931b, p. 821); Udden (1919, p. 127).
Bureau of Economic Geology files.

County.—Bexar.

Well name.—J. M. West No. 1 Timberlake.

Location.—J. M. Urrighas survey; 1,650 feet FWL, 1,900 feet FNL; ¼ mi. N of Alta Vista.

Elevation.—573 feet. *Total depth.*—4,630 feet. *Completed.*—1948.

Top of metamorphic rocks.—4,240 feet. *Elevation of metamorphic rocks.*— –3,667 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4243–53 (2), 4263–73, 4310–20, 4420–30, 4500–10, 4600–10.

Description of metamorphic rocks.—The sequence is composed of rutiliferous graphitic chlorite-sericite phyllite and phyllitic metaquartzite; metamorphism is low grade with a high shearing element; principal structures are foliation, grain stretching, microfolding, contortion, and flowage around augen of quartz. The rocks are penetrated by both pre- and post-deformation quartz veins and probably the quartz augen are broken veins.

This well penetrated the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957; J. R. Sandidge, Magnolia Petroleum Company, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Blanco.

Well name.—Roland K. Blumberg No. 1 Wagner.

Location.—Henry Manton League; 1,980 feet FWL, 1,320 feet FSEL (of lease).

Elevation.—1,250 feet (from topographic map). *Total depth.*—3,318 feet. *Completed.*—1955.

Top of Paleozoic rocks.—130 feet. *Elevation of Paleozoic rocks.*— +1,120 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—This well penetrated Ellenburger rocks directly beneath the Cretaceous. According to Barnes (1956), top of Ellenburger is 130 feet, top of Cambrian sequence is at 1,940 feet, and at 3,318 feet, total depth, the well is in the Cambrian Hickory sandstone.

This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1959, p. 348).
Personal communication: V. E. Barnes, Bureau of Economic Geology, 1956; Robert Pavlovic, Magnolia Petroleum Company, 1955.

County.—Blanco.

Well name.—Theodore Hicks No. 1 Albert Specht.

Location.—T. M. Fowler survey; 273 feet FWL, 3,355 feet FSL; 22 mi. S of Johnson City.

Elevation.—1,330 feet. *Total depth.*—1,635 feet. *Completed.*—1931.

Top of Paleozoic rocks.—690 feet. *Elevation of Paleozoic rocks.*— +640 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 718–80, 1180–1240, 1250, 1380, 1430, 1480.

Description of Paleozoic rocks.—Descriptions in the files of the Bureau of Economic Geology report dark sandy shale, 690 to 1,270 feet, and red and green shale, 1,270 to 1,430 feet. Sellards (1933) described these samples as "altered shale." The sequence consists of dark sheared and brecciated chert invaded by vein quartz and containing dark organic material, dark argillaceous and micaceous siltstone, dark silty shale, locally pyritic, and red hematitic shale. The shales are invaded by quartz veinlets, and locally small blebs of new chlorite indicate incipient metamorphism. Carbonized plant fragments and spore fragments were noted in some of the cuttings. The shale in the 1,430-foot interval contains ellipsoidal grains of "pleochroic" carbonate, possibly siderite, similar to that seen in Turner No. 1 Linder in Kendall County. In general, the section consists of unmetamorphosed Ouachita facies rocks. A small fragment of microgabbro in the 1,430-foot interval is probably the result of contamination.

This well penetrated Ouachita facies rocks of probable lower Paleozoic age in the frontal zone of the Ouachita belt.

X-ray data.—I > K > ML > Ch; 10/7 ⌢ 0.9; SR = 1.75. Chlorite-illite shales of Ouachita structural belt type but these shales contain more kaolinite than is found in wells in the northern limb of the belt.

References.—Barnes (1948); Sellards (1933, p. 188).
Bureau of Economic Geology files.
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Blanco.

Well name.—Johnson (R. A. Rodson et al.) No. 1 Glasscock.

Location.—W. W. McDonald survey; 600(?), 1,156(?) feet FNL, 600(?), 859(?) feet FWL; 8 mi. N of Blanco, 6.8 mi. S of Johnson City.

Elevation.—1,300 feet (from topographic map). *Total depth.*—1,005(?) feet; 968(?) feet. *Completed.*—Before 1932.

Top of Paleozoic rocks.—704 feet. *Elevation of Paleozoic rocks.*— +596 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 954–958.

Description of Paleozoic rocks.—According to Barnes (1956), this well encountered Ordovician Ellenburger beds directly beneath the Cretaceous. The single section examined for this study was Ellenburger dolomite.

This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1948); Sellards (1933, p. 192).
Personal communication: V. E. Barnes, Bureau of Economic Geology, 1956; J. B. Souther, Pan American Petroleum Corporation, 1955.

County.—Blanco.

Well name.—Johnson City Oil Company No. 1 Waller (also known as Winan & Forbes No. 1 Bruckner, Bruckner Water Well).

Location.—Z. J. Hemphill survey; 1 mi. S of Johnson City.

Elevation.—1,250 feet. *Total depth.*—1,552 feet. *Completed.*—1929 and 1933.

Top of Paleozoic rocks.—240 feet. *Elevation of Paleozoic rocks.*— +1,010 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—First sample at 240 feet is Ellenburger; last sample at 1,255 feet is Ellenburger. This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1948); Sellards (1933, p. 192).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Blanco.

Well name.—Lile and Adams No. 1 Leeder (also known as Adams & Lyles No. 1 Leeders).

Location.—Noel Nixon survey; 2¼ mi. N, 3 mi. W of Blanco.

Elevation.—ni. *Total depth.*—530 feet. *Completed.*—Before 1932.

Top of Paleozoic rocks.—405 feet. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—According to Barnes (1956), the entire Paleozoic section penetrated is Ellenburger.

This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1948); Sellards (1933, p. 192).
Personal communication: V. E. Barnes, Bureau of Economic Geology, 1956.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Blanco.

Well name.—D. J. Meeks No. 1 E. W. Walker.

Location.—Noel Nixon survey; 4,445 feet FNL, 1,000 feet FWL; 1½ mi. E of Blanco.

Elevation.—1,400± feet (from topographic map). *Total depth.*—1,075 feet. *Completed.*—1931.

Top of Paleozoic rocks.—635 feet. *Elevation of Paleozoic rocks.*— +765± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 660, 800, 900.

Description of Paleozoic rocks.—According to Barnes (1956), this well penetrated a Pennsylvanian sandstone and shale.

The sequence is composed of dark shale, locally sandy, silty, calcareous, micaceous, and fine-grained, angular to subround, very poorly sorted, calcareous argillaceous slightly feldspathic silty quartz sandstone; these rocks are probably Atoka.

The well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: V. E. Barnes, Bureau of Economic Geology, 1956.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Blanco.

Well name.—E. L. Nixon No. 3 C. E. Crist.

Location.—John McClenechen survey; 3 mi. SE of Blanco.

Elevation.—1,400± feet. *Total depth.*—1,264± feet. *Completed.*—ni.

Top of Paleozoic rocks.—500± feet. *Elevation of Paleozoic rocks.*— +900± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in files of the Bureau of Economic Geology are as follows: below 1,082 feet, dark greenish finely micaceous siltstone; 1,264 feet, dark shale and fine-grained quartzitic sandstone.

This well probably penetrated Pennsylvanian beds of Atoka age close to the Ouachita front.

X-ray data—None.

References.—Bureau of Economic Geology files.

County.—Blanco.

Well name.—E. L. Nixon No. 2 Hohenberger.

Location.—Q. C. Stephens survey; 4 mi. S of Blanco.

Elevation.—1,460 feet (from topographic map.). *Total depth.*—1,191 feet. *Completed.*—1937.

Top of Paleozoic rocks.—470 feet. *Elevation of Paleozoic rocks.*—+990 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in Bureau of Economic Geology files report Ellenburger directly beneath Cretaceous rocks at 470 feet.

This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Bosque.

Well name.—American Liberty Oil Company No. 1 Clanton.

Location.—William McFarland survey; 660 feet FNL, 660 feet FEL; 1 mi. S of Iredell.

Elevation.—981 feet, derrick floor; 972 feet, ground. *Total depth.*—6,995 feet. *Completed.*—1949.

Top of Paleozoic rocks.—530 feet. *Elevation of Paleozoic rocks.*—+451 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1900–30, 2320–50, 2770–00, 2980–10, 3580–3600, 4150–80, 4330–60, 4620–30 (2), 5060–70.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Pennsylvanian, 650± feet; top of Marble Falls, 4,330 feet; top of Barnett, 4,618 feet; top of Ellenburger, 4,720 feet; total depth 6,982 feet, in Ellenburger.

Petrographically, the sequence is divided into the following gross units: (1) fine-grained, angular to subround, fairly well-sorted, slightly argillaceous (chloritic) and feldspathic quartz sandstone, locally calcareous, locally dolomitic, angular to subangular micaceous quartz siltstone, and very dark silty shale; (2) dark, fine-grained, slightly glauconitic calcareous spiculite and black spiculitic and calcareous shale; and (3) fine-grained, equigranular dolomite and slightly fossiliferous and pelletiferous calcilutite. Unit (1) is Atoka, unit (2) is Marble Falls—Barnett—both rich in dark organic material—and unit (3) is Ellenburger.

This well penetrated rocks of foreland facies west of the Ouachita structural belt.

X-ray data.—I > Ch > ML > K; 10/7 ∼ 1; F = 20; SR = 2.0.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; Robert Roth, Humble Oil & Refining Company, 1955.

County.—Bosque.

Well name.—American Liberty Oil Company (Southland Oil Company) No. 1 R. T. Greenwade.

Location.—Mary Cole survey; 660 feet FSL, 8,752 feet FEL; 10 mi. E of Whitney.

Elevation.—664 feet, derrick floor. *Total depth.*—7,231 feet. *Completed.*—1949.

Top of Paleozoic rocks.—720 feet. *Elevation of Paleozoic rocks.*— -56 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 6800–10, 7110–20.

Description of Paleozoic rocks.—Goldstein (1955) reported top of "Atokan" Smithwick, 720 feet; top of Ellenburger, 7,192 feet; total depth 7,230 feet, in Ellenburger. Thin sections show fine-grained, angular, poorly sorted, dolomitic feldspathic quartz sandstone (6800–6810) and black spiculitic calcareous shale (7110–7120). The deeper sample is Marble Falls—Barnett.

This well penetrated foreland rocks west of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Bosque.

Well name.—American Liberty Oil Company No. 1 Reichert.

Location.—Joseph Harlan survey; 660 feet FNL, 2,850 feet FEL; 7 mi. NW of Valley Mills.

Elevation.—852 feet, derrick floor. *Total depth.*—8,000 feet. *Completed.*—1948.

Top of Paleozoic rocks.—1,150 feet. *Elevation of Paleozoic rocks.*— -298 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3970–80, 4360–70.

Description of Paleozoic rocks.—Goldstein (1955) reported top of "Atokan" Smithwick, 6,730 feet; top of Big Saline, 6,830 feet; top of Ellenburger, 6,900 feet; total depth 8,000 feet, in Ellenburger.

Thin sections and samples examined for this study show a sequence of dark silty shale, fine-grained subangular to subround, fairly well-sorted, slightly argillaceous and feldspathic quartz sandstone and angular to subangular chloritic micaceous quartz siltstone. The sandstones are Atoka type.

This well penetrated foreland facies rocks west of the Ouachita belt.

X-ray data.—I > ML > Ch (K = Tr?); 10/7 ∼ 1.2; F = 20; SR = 1.50.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; Robert Roth, Humble Oil & Refining Company, 1955.

County.—Bosque.

Well name.—Coleman and Wasson Oil Company No. 1 R. M. Cox.

Location.—Ross McClellan survey; ½ mi. S of Walnut Springs.

Elevation.—1,000 feet (from topographic map). *Total depth.*—3,960 feet. *Completed.*—1920.

Top of Paleozoic rocks.—1,000± feet. *Elevation of Paleozoic rocks.*—Sea level datum±.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3900–4000.

Description of Paleozoic rocks.—Notes in files of the Bureau of Economic Geology describe the rocks from 3,900 to 4,000 feet as dark shale and hard quartzitic sandstone; top of Paleozoic, as interpreted from driller's log, is 1,000± feet.

The single sample examined for this study is a fine-grained, angular to subround, fairly well-sorted, slightly calcareous, argillaceous and feldspathic quartz sandstone, containing fragments of dark shale, chert, slate-phyllite, and quartz mosaic.

This well penetrated Atoka beds west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Bosque.

Well name.—Profit No. 1 Henry.

Location.—Amon B. King survey; ½ mi. S of Mosheim.

Elevation.—1,150 feet. *Total depth.*—6,224 feet. *Completed.*—1953.

Top of Paleozoic rocks.—1,060 feet. *Elevation of Paleozoic rocks.*— +90 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—The following information is from scout reports: base of Cretaceous and top of Pennsylvanian, 1,060 feet; top of Strawn, 2,952 feet; top of Ellenburger, 5,815 feet. The reported "Strawn" is probably Atoka.

This well is located west of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: H. A. Sellin, Magnolia Petroleum Company, 1958.

County.—Bosque.

Well name.—Telegram Oil Company No. 1 J. W. Burns.

Location.—Justin Castanie (Castino) survey.

Elevation.—700± feet (from topographic map). *Total depth.*—4,575 feet. *Completed.*—1922.

Top of Paleozoic rocks.—1,000±(?) feet. *Elevation of Paleozoic rocks.*— -300±(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in the files of the Bureau of Economic Geology report black shale, gray sandstone, and light-colored sandstone between 4,310 and 4,500 feet; top of Paleozoic, as interpreted from driller's log, is 1,000± feet.

This well probably penetrated Atoka beds west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Bosque.

Well name.—Telegram Oil Company No. 1 M. B. Myrick.

Location.—Martha Baker survey; 4 mi. NW of Kopperl.

Elevation.—610 feet. *Total depth.*—6,100 feet. *Completed.*—1925.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4825(?), 5800.

Description of Paleozoic rocks.—Notes in the files of the Bureau of Economic Geology report the well in Pennsylvanian at 4,700 feet and describe a series of samples between 4,700 and 6,100 feet, total depth, as black shale, gray sandstone, and some clear quartz.

Petrographic study shows a sequence of dark silty shale, fine-grained argillaceous quartz siltstone, locally micaceous, and fine-grained, angular to subround, fairly well-sorted, argillaceous quartz sandstone, locally calcareous, micaceous, chloritic; the sandstone contains fragments of shale, chert, and slate-phyllite.

This well penetrated Atoka beds west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Bosque.

Additional well not shown on the map (Pl. 2) and not studied because of lack of samples or basic data:

SINCLAIR OIL AND GAS COMPANY No. 1 A. M. WHITE—

Location: Joseph Taylor survey, NW corner. *Completed:* 1919. *Top of Paleozoic rocks:* from driller's log, 1,200± feet.

County.—Bowie.

Well name.—A. M. Sutton No. 1 J. G. Newkirk.

Location.—Jessie Dean survey; 500 feet FSL, 1,980 feet FWL; 9 mi. NW of DeKalb.

Elevation.—390 feet. *Total depth.*—ni. *Completed.*—ni.

Top of Paleozoic rocks.—4,170 feet. *Elevation of Paleozoic rocks.*— -3,780 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 3895, 4250, 4293.

Description of Paleozoic rocks.—Base of Cretaceous and top of Paleozoic (Stanley?) is reported at 4,170 feet (Goldstein, 1955). Thin section studies show that the sequence is composed of fine-grained, angular, poorly sorted, argillaceous micaceous feldspathic quartz sandstone (or metasandstone) and calcareous micaceous siltstone (or metasiltstone) invaded by fine quartz veinlets; the rocks show incipient to very weak metamorphism.

This well penetrated Stanley(?) southeast of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Bowie.

Well name.—J. K. Wadley No. 1 E. Blackman.

Location.—J. C. Hays survey; 1,190 feet FNL, 466 feet FWL; 3½ mi. N of Malta.

Elevation.—355 feet. *Total depth.*—5,548 feet. *Completed.*—1955.

Top of Paleozoic rocks.—5,460 feet. *Elevation of Paleozoic rocks.*— -5,105 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—ni.

X-ray data.—None.

References.—Gatling (1956, p. 1237).
Personal communication: B. W. Fox, The Atlantic Refining Company, 1956.

County.—Bowie.

Well name.—J. K. Wadley No. 1 Bentley Johnson.

Location.—John Tisdale survey; 1,800 feet FNL, 1,400 feet FEL; 6 mi. N of Malta.

Elevation.—354 feet. *Total depth.*—5,091 feet. *Completed.*—1955.

Top of Paleozoic rocks.—5,003 feet. *Elevation of Paleozoic rocks.*— —4,649 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 5020–30, 5070–80.

Description of Paleozoic rocks.—Thin sections are fine-grained angular to subround, poorly sorted, argillaceous feldspathic quartz sandstone; in the 5,070 to 5,080-foot interval the sandstone is veined with calcite and has a calcareous matrix. These rocks are probably Stanley. There is no metamorphism.

This well penetrated Stanley(?) southeast of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Gatling (1956, p. 1237).
Personal communication: B. W. Fox, The Atlantic Refining Company, 1956.

County.—Brewster.

Well name.—Brewster No. 1 Fee.

Location.—Section 45, block G-15, GC&SF survey.

Elevation.—3,199(?) feet. *Total depth.*—1,935 feet. *Completed.*—1930.

Top of Paleozoic rocks.—100± feet. *Elevation of Paleozoic rocks.*—+3,099±(?) feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 415–25 (2), 425–35, 435–50 (2), 450–75 (2), 475–540 (2), 540–75, 575–615 (2), 620–40, 640–45, 645–65, 665–75 (2), 675–700 (3), 720–95, 795–05, 805–60, 860–925, 925–85 (2), 1080–00, 1100–1230, 1230–50 (2), 1250–70 (2), 1275–00 (2), 1300–10, 1310–50, 1350–70, 1375–90, 1390–95, 1400–05, 1405–10, 1425–30, 1450–00, 1500–25, 1550–60, 1600–25 (2), 1625–50, 1675–00, 1700–25, 1800–25, 1850–70 (2), 1870–85 (2).

Description of Paleozoic rocks.—According to Olson (1958), this well penetrated Marathon limestone, probably dipping steeply.

The sequence is composed of: (1) dark, very fine-grained, angular to subround, fairly well-sorted, dolomitic and calcareous feldspathic quartzitic quartz sandstone and siltstone, locally containing bitumen, locally pyritic, micaceous, and rich in heavy minerals (layers of abundant leucoxene, tourmaline, zircon, rutile); the rocks are veined with calcite, quartz, and streaks of bituminous material; locally calcite is very abundant and the fine-grained sandstone grades into a silty and sandy limestone or dolomitic limestone; the feldspar is plagioclase and commonly so abundant that the rock is an arkose; in some sections the rocks show dimensional grain orientation and mica orientation, calcite is commonly twinned, and in some fragments there is severe crushing; (2) very dark shale, commonly containing dark organic material, locally silty, micaceous, dolomitic, or calcareous.

Although the calcite is commonly twinned extensively, the rocks do not appear to be metamorphosed except for local incipient to very weak metamorphism in zones of more intense shearing.

The sequence is identified as lower Paleozoic Ouachita facies, probably a clastic and siliceous facies of the Marathon limestone.

X-ray data.—None.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1958.

County.—Brewster.

Well name.—Dodson (Hinton) No. 1 Texas American Syndicate.

Location.—Section 66, block 10, GH&SA survey; 660 feet FNL, 660 feet FEL.

Elevation.—4,233 feet. *Total depth.*—9,055 feet. *Completed.*—1944.

Top of Paleozoic rocks.—875 feet. *Elevation of Paleozoic rocks.*— +3,358 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—The following information is taken from a sample log: base of Cretaceous, and top of Triassic (Bissett), 875 feet; top of Paleozoic (Capitan?), 1,125(?) feet; igneous intrusion, 4,455 to 4,710 feet [analcite microsyenite, Flawn, 1956]; top of Mississippian(?), 5,120 feet; top of Devonian, 5,665 feet; top of Montoya, 6,000 feet; igneous intrusion, 6,078 to 6,458 feet [aegirine-arfvedsonite microgranite, Flawn, 1956]; top of Simpson, 6,680 feet; top of Ellenburger, 8,350 feet.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Flawn (1956, p. 65).
Personal communication: J. P. Olson, Shell Oil Company, 1958.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Brewster.

Well name.—John C. Grasdorf (Grostorf) No. 1 Trans-Pecos Oil and Gas Company.

Location.—Section 18, block G-15, GC&SF survey; 920 feet FNL, 2,500 feet FEL; SE of Horseshoe Mountain.

Elevation.—3,073 feet. *Total depth.*—2,820 feet. *Completed.*—1933.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1900–10, 2350–60, 2730–45.

Description of Paleozoic rocks.—The sequence is composed of fine-grained, dark, locally graphitic, siliceous dolomite and dolomitic chert, brecciated and sheared, and veined with quartz-carbonate-bitumen. This well penetrated lower Paleozoic (probably Ordovician) Ouachita facies rocks just south of the Marathon Basin.

X-ray data.—(1) 1,900 feet: Ch $>$ I; 10/7 $\sim$ 0.3. (2) 2,730 feet: I $>$ Ch; 10/7 $\sim$ 4; F $=$ 20; SR $=$ 7.0.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1958.

County.—Brewster.

Well name.—Gulf Oil Corporation No. 1 D. S. C. Coombs.

Location.—Section 16, block 4, GC&SF survey; 660 feet FSL, 1,980 feet FEL; 1 mi. SE of Marathon.

Elevation.—4,114 feet, derrick floor. *Total depth.*—9,500 feet. *Completed.*—1956.

Top of Paleozoic rocks.[36] *Elevation of Paleozoic rocks.*— +4,114 feet.

Thin section coverage (depth in feet)—SHELL OIL COMPANY: 2900–05 (5), 3880 (7), 3900 (2), 4000 (2), 4020, 4850–00, 5830 (2), 6200 (2), 9370 (4).

Description of Paleozoic rocks.—Wilson (1957) reported as follows: The well was spudded in Woods Hollow shale; top of Fort Peña, 320 feet; top of Alsate, 710 feet; top of Marathon, 810 feet; top of Dagger Flat, 4,840 feet; base of thrust plate in interval 5,840 to 6,100 feet (samples missing); 6,100 feet to total depth, Pennsylvanian-type sandstone and shale. Andesitic(?) intrusions occur in the

[36] Well was spudded in Woods Hollow shale.

interval 3,870 to 3,910 feet; trilobites of Marathon age (Lower Ordovician) were found at 4,050 feet in the thrust plate, and fusulinids of Pennsylvanian and Wolfcamp(?) age occur in beds beneath.

Thin section examination gives the following information: 2,900–2,905 feet, very fine-grained dolomitic limestone; 3,880, 3,900, 4,000, 4,020 feet altered andesite(?); 4,850–4,900 feet, fine-grained sandy intraclastic limestone; 5,830 feet, fine-grained sandy limestone, indications of metamorphism in extensively twinned calcite; 6,200 feet, fine-grained, angular to subangular, fairly well-sorted, tightly packed, dolomitic feldspathic quartz sandstone of Mississippian-Pennsylvanian (foreland?) type; 9,370 feet, angular to subround, fairly well-sorted, feldspathic quartz sandstone, locally tightly packed, locally slightly argillaceous, dolomitic, cherty.

This well penetrated lower Paleozoic Ouachita facies rocks, intersected a thrust fault, and bottomed in strata of probable Mississippian-Pennsylvanian age and foreland type; it supports the concept that at least the north part of the Marathon salient is an allochthonous plate.

X-ray data.—None.

References.—Personal communication: J. D. Moody, Gulf Oil Corporation, 1957; J. L. Wilson, Shell Oil Company, 1957.

County—Brewster.

Well name.—King & Franklin No. 1 A. S. Gage.

Location.—Section 138, block 22, GH&SA survey; 7 mi. SE of Marathon.

Elevation.—4,244 feet. *Total depth.*—1,613 feet. *Completed.*—1935.

Top of Paleozoic rocks.[37] *Elevation of Paleozoic rocks.*— +4,244 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 130–40, 255–62, 290–95, 335–41, 508–12, 835–39, 885–90, 929–30, 934–38, 1086–90, 1100–05, 1112–15, 1131–35, 1190–93, 1193–98, 1215–21.

Description of Paleozoic rocks.—According to Goldstein (1955) there are three interpretations of the section penetrated in this well:

Baker and Carsey (King, 1937)	*(Feet)*	*Spangler and Fulk* (1942)	*(Feet)*	*Goldstein*	*(Feet)*
Fort Peña	0–114	Quaternary	0–114	Middle and Lower Ordovician	0–1060
Alsate	114–465	Tesnus	114–1060		
Marathon	465–1613	Caballos	1060–1565	Caballos	1060–1516

The sequence from the surface to 1,060 feet consists of gray calcareous silty shale, locally dolomitic and locally containing calcareous spines, clay pellets, and a trace of glauconite, and calcareous argillaceous siltstone, overlying fine-grained, subangular, fairly well-sorted, tightly packed, calcareous quartzitic sandstone, locally fossiliferous. The intervals 927 to 930 and 934 to 938 feet are fine-grained fossiliferous calcareous dolomite. Veinlets of quartz, carbonate, and bituminous material are common. The deeper part of the well from 1,060 feet to total depth is composed mostly of siliceous rocks, chiefly dark argillaceous microgranular to microspherulitic chert locally containing abundant organic material; the cherts are commonly fractured and brecciated. The rocks are unmetamorphosed Ouachita (Marathon) facies.

This well spudded in lower Paleozoic Ouachita facies rocks and bottomed in rocks of the same age and facies. If Goldstein's interpretation is correct, there is a thrust fault in the sequence.

X-ray data.—None.

References.— P. B. King (1937, p. 29); Spangler and Fulk (1942).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Brewster.

Well name.—Plumber and Schwab No. 1 Bud Roark.

Location.—Section 64, block G-18, TC survey.

Elevation.—2,172 feet. *Total depth.*—3,007 feet. *Completed.*—ni.

Top of metamorphic rocks.—1,848 feet. *Elevation of metamorphic rocks.*— +324 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1848–65 (2), 1865–20, 1920–60, 1960–00, 2000–10, 2110–55, 2155–05 (2), 2241–85, 2288–20, 2320–62, 2362–10, 2410–47, 2447–93 (2), 2536–74, 2574–00, 2600–40, 2640–65, 2665–31 (2), 2731–60, 2750–57, 2804–33, 2933–35, 2938–77, 2977–07 (2). BUREAU OF ECONOMIC GEOLOGY: 1865, 2000, 2205, 2535, 2804, 3007.

[37] Well was spudded in Ouachita (Marathon) facies rocks.

Description of metamorphosed Paleozoic(?) rocks.—The sequence in this well is composed of: (1) dark gray to black rutiliferous graphitic sericite-chlorite-quartz phyllite and black pyritic rutiliferous siliceous (finely quartzose) graphitic slate; (2) very fine-grained graphitic dolomitic metaquartzite, locally sericitic (phyllitic), calcareous, rutiliferous, locally feldspathic in the lower part of the well; and (3) below 2,600 feet in the lower part of the sequence, fine-grained siliceous (finely quartzose) dolomitic calcite marble, locally pyritic, graphitic. Dolomitic metachert occurs in the 3,007-foot interval. Metamorphism is weak to low grade with a strong shearing element in certain intervals; foliation is expressed in stretched quartz and calcite grains and orientation of graphitic streaks; locally the phyllites show wrinkling. Some of the fine-grained metaquartzite samples in the lower part of the sequence show relict round sand grains in a mosaic of finer quartz.

This well penetrated metamophosed rocks of the interior zone, but metamorphism is not so advanced as in other wells in this belt or as in the Sierra del Carmen outcrop in Coahuila, Mexico. The nature of the rocks suggests that the well encountered a weakly metamorphosed sequence of pre-Tesnus Marathon facies rocks, possibly a southern facies of the Marathon limestone similar to that exposed in the Dagger Flat area of the Marathon Basin. This is significant in that it suggests a Paleozoic age for the more metamorphosed rocks to the south and east.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Brewster.

Well name.—Pure Oil Company No. 1 Massie West.

Location.—Section 548, block 8.

Elevation.—5,026 feet. *Total depth.*—5,634 feet. *Completed.*—1956.

Top of Paleozoic rocks.—3,520 feet. *Elevation of Paleozoic rocks.*— +1,506 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—This well was spudded in volcanic rocks, drilled through Permian and Ellenburger beds, and bottomed in Precambrian granite (Culbertson et al., 1957). It is located west of the Ouachita structural belt (cf. Sun Oil Company No. 1 McElroy).

X-ray data.—None.

References.—Culbertson et al. (1957, p. 1128).

County.—Brewster.

Well name.—Sun Oil Company No. 1 McElroy.

Location.—Section 5, block 212, T&STL survey; 2,300 feet FNL, 2,100 feet FEL.

Elevation.—3,708 feet, derrick floor. *Total depth.*—8,455 feet. *Completed.*—1955.

Top of Paleozoic rocks.—2,495(?) feet, 2,570(?) feet. *Elevation of Paleozoic rocks.*— +1,213(?) feet, +1,138 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Olson (1960) reported that probably more than 1,000 feet of lower Paleozoic Ouachita facies rocks overlie a normal foreland sequence. Lithologies include chert conglomerate, dark green and gray shale, dark siliceous argillaceous limestone, and varicolored cherts. Dips in cores range from 35° to vertical. Identification of formations is difficult; the interval 2,495 feet (or 2,570 feet) to about 2,850 feet resembles Fort Peña and the interval 2,850 feet to about 3,760 feet resembles Woods Hollow. If these tentative identifications are correct the sequence is overturned. Rocks in the interval 3,760± feet to 5,536 feet are probably Wolfcamp but may include Pennsylvanian beds as well. The following stratigraphic data are taken from an earlier report by Zimmerman (1957): top of Woodford, 5,536 feet; top of Silurian-Devonian, 5,613 feet; tentative top of Montoya, 6,288 feet; tentative top of Ellenburger, 7,244 feet; top of basal Ellenburger sand (Cambrian?), 8,292 feet; total depth 8,456 feet.

This well penetrated lower Paleozoic Ouachita facies rocks, transected a thrust fault (westward extension of the Dugout Creek overthrust?) and bottomed in foreland facies rocks. The well is probably located just south of the Ouachita front. The relatively thin Permo-Pennsylvanian(?) sequence suggests uplift (and erosion?) prior to overthrusting.

X-ray data.—None.

References.—Personal communication: D. A. Zimmerman, Sun Oil Company, 1957; John P. Olson, Shell Oil Company, 1960.

County.—Brewster.

Well name.—Fred Turner, Jr., No. 1 D. S. C. Coombs et al.

Location.—Section 37, block 21, GH&SA survey; 433 feet FSL, 2,406 feet FWL.

Elevation.—3,469 feet, derrick floor. *Total depth.*—13,980 feet. *Completed.*—1957.

Top of Paleozoic rocks.[38] *Elevation of Paleozoic rocks.*— +3,469 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 90–100, 200–10, 700–10, 840–50, 1400–10, 1530–40, 1610–20, 2120–30 (2), 2590–00 (2), 2730–40, 2960–70, 3230–40, 3290–00, 4090–00, 4580–90, 5300–10, 5850–60, 6690–00, 7190–00, 8690–00, 9480–90, 10,690–00, 12,010–20, 13,970–80.

Description of Paleozoic rocks.—According to Merkt (1958), this well was spudded in Dagger Flat sandstone.

From the surface to about 1,600 feet the sequence is composed of interbedded sandstone and shale. The sandstone is gray, fine- to medium-grained, angular, poorly sorted to fairly well-sorted, feldspathic quartz sandstone or arkose containing a trace of glauconite, commonly dolomitic or calcareous, locally micaceous, argillaceous, quartzitic, pyritic; the rock is veined with quartz, carbonate, and bituminous material; the mica is mostly faded biotite, potassium feldspar is subordinate to plagioclase, and some samples contain phosphatic fragments. The shale is dark slightly glauconitic silty shale, locally brecciated and deformed. Locally in the sequence the calcareous sandstone grades into silty and sandy limestone.

From 1,600 to 13,980 feet (total depth) the sequence consists of interbedded shale, limestone, and sandstone. In the upper part of the section, shale and limestone predominate and sandstone beds are few; sandstone increases downward and below 8,400 feet the section is mostly shale and sandstone with minor limestone. Chert (including siliceous shale) is present between 2,120 and 3,300 feet. The rock types are as follows: (1) dark very fine granular dolomitic limestone (intraclasts cemented by sparry calcite), locally siliceous, argillaceous, silty or sandy, pyritic, containing dark organic material, in some intervals containing fossil fragments (2,730 to 2,740 feet—spines and shells), veined by twinned sparry calcite, dolomite, bituminous material, and quartz or fine silica; (2) very fine-grained calcilutite, locally dolomitic, pelletiferous, sandy or silty, veined by twinned sparry calcite; (3) fine granular dolomite, veined by dolomite and twinned sparry calcite; (4) dark cryptocrystalline chert, commonly dolomitic or calcareous, locally argillaceous, locally containing dark organic material, veined with twinned sparry calcite, quartz, bituminous material; (5) dark shale, commonly very finely dolomitic, locally sandy or silty, siliceous, rich in dark organic matter, veined by twinned sparry calcite, quartz, bituminous material, locally brecciated and deformed; (6) gray fine-grained mostly angular (subround in some intervals) poorly sorted to fairly well-sorted calcareous and dolomitic feldspathic quartz sandstone or arkose, locally quartzitic, micaceous, argillaceous, locally containing dark organic matter and traces of glauconite, veined by twinned sparry calcite, dolomite, quartz, and bituminous material.

The samples are very fine; toward the bottom of the hole there is a mixed sample suite that shows little variation; possibly the sequence is very thin bedded and standing at a high angle, possibly there has been a mixing of samples in the mud stream.

This well appears to have penetrated a long sequence of lower Paleozoic Ouachita facies rocks (Cambro-Ordovician); the sandstones (containing potassium feldspar, glauconite) do not resemble the late Paleozoic sandstones of the area.

X-ray data.—(1) 840 feet: Ch > ML > I; 10/7 ∼ 0.4; F = 20; SR = 1.3. (2) 13,970 feet: I > Ch; 10/7 ∼ 0.6; F = 20, 25; SR = 2.3.

References.—Personal communication: E. E. Merkt, Gulf Oil Corporation, 1958.

County.—Brewster.

Well name.—Woods Oil and Gas Company No. 1-47 Mary Decie et al. (also known as Slick-Urschel Oil Company No. 1 Mary Decie-Sinclair).

Location.—Section 47, block 4, GC&SF survey; 6 mi. W, 3 mi. N of Marathon.

Elevation—4,461 feet. *Total depth.*—9,741 feet. *Completed.*—1956.

Top of Paleozoic rocks.[39] *Elevation of Paleozoic rocks.*— +4,461 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Galley (1957) reported that the well spudded in Caballos novaculite and encountered the base of the Caballos at 160 feet; beneath the Caballos is a continuous section of normal foreland facies rocks including Permian, Pennsylvanian, Mississippian, Woodford, Devonian, Fusselman, Montoya, Simpson, and Ellenburger; top of Ellenburger, 9,400 feet; total depth, in Ellenburger. Woods (1957) remarked that the well started in a klippe of Caballos and cut several thrust sheets in the upper section. Hull (1957b) noted that the Wolfcamp series is folded and faulted: top of Wolfcamp, 165 feet; base of Wolfcamp, 6,820 feet overlying Strawn. He said: "These 6,655 . . . feet of shale, fine-grained sandstone, and fragmental limestone [Wolfcamp] were deposited in a basin and then folded before the Wolfcamp formation at Wolf Camp Hills was deposited."

[38] Well was spudded in Dagger Flat sandstone.
[39] Well was spudded in Caballos movaculite.

The following log is given in the West Texas Geological Society Field Trip Guidebook for the Glass Mountains area, 1957: spudded in Caballos novaculite, Dugout Creek overthrust, 160 feet; top of Gaptank formation of Wolfcamp age, 160 feet; possible thrust fault (sole thrust of Marathon Basin allochthonous plate?), 1,600 feet; top of Strawn, 6,820 feet; top of Woodford, 6,980 feet; top of Siluro-Devonian, 7,270 feet; top of Montoya(?), 8,070 feet; top of Simpson, 8,250 feet; top of Ellenburger, 9,385 feet; total depth, 9,637 feet, in Ellenburger.

This well is important to the structural interpretation of the Marathon salient in that (a) it demonstrates a foreland facies section beneath overthrust Ouachita (Marathon) facies beds, and (b) it suggests that there are deformed Wolfcamp beds older than those exposed in the Wolfcamp Hills (p. 54).

X-ray data.—None.

References.—Hull (1957b, p. 96); Anonymous (1957, p. 13).
Personal communication: J. E. Galley, Shell Oil Company, 1957; R. D. Woods, Humble Oil & Refining Company, 1957.

County.—Burnet.

Well name.—Al Belanger No. 1 Nella T. Evans.

Location.—Spicewood area, 10 mi. E of Marble Falls.

Elevation.—925 feet (from topographic map). *Total depth.*—734(?) feet. *Completed.*—ni.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology report Marble Falls limestone at 526 to 704 feet, Barnett shale at 704 to 728 feet, and Ellenburger dolomite at 728 to 734 feet.

Apparently this well penetrated foreland rocks close to the edge of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Burnet.

Well name.—Bertram City Well No. 1.

Location.—Bertram, Texas.

Elevation.—1,265 feet. *Total depth.*—2,395 feet. *Completed.*—ni.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2320–25, 2385–88.

Description of Paleozoic or metamorphic rocks.—A driller's log in the files of the Bureau of Economic Geology reports "schist" from 1,767 to 2,395 feet and quartzite in a core from 2,395 feet. The location of the well suggests that the identification of "schist" is probably in error. The two samples available for study are dark silty micaceous shale containing carbonaceous debris and very fine carbonate; the rocks are deformed and locally show two orientations of mica intersecting at a high angle. These rocks are probably deformed Atoka beds lying close to the Ouachita front (Pl. 2).

X-ray data.—$I > ML > Ch > K$; $10/7 \sim 1.5$; $F = 20$; $SR = 1.55$.

References.—Bureau of Economic Geology files.

County.—Burnet.

Well name.—E. A. Dunham and Hensman Drilling Company No. 1 W. F. Day.

Location.—GC&SF survey; 330 feet FSL, 330 feet FWL; 9 mi. NE of Briggs.

Elevation.—919 feet. *Total depth.*—4,790 feet. *Completed.*—1955.

Top of Paleozoic rocks.—450 feet. *Elevation of Paleozoic rocks.*—+469 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—A sample log in the Bureau of Economic Geology files reports base of Cretaceous, 450 feet; Pennsylvanian shale, 450 to 2,390 feet; Ellenburger, 2,390 to 4,790 feet (total depth). Sample descriptions in files of Bureau of Economic Geology indicate that the interval 450 to 2,390 feet includes Atoka resting on Marble Falls—Barnett.

This well penetrated foreland rocks west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.
Personal communication: E. J. Theessen, Shell Oil Company, 1956.

County.—Burnet.

Well name.—Twin Cities Oil and Gas Company No. 1 Taylor.

Location.—3 mi. E of Victor Lake on Rocker ranch, 8 mi. N of Bertram.

Elevation.—1,382 feet. *Total depth.*—2,300 feet. *Completed.*—1920.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet.).—None.

Description of Paleozoic rocks.—A sample log in the Bureau of Economic Geology files reports the following information: in Smithwick at 465 feet, in Ellenburger at 570 feet. Sample descriptions in files of the Bureau of Economic Geology indicate that the intervals 465, 488, and 500 feet are Marble Falls—Barnett. Sellards (1933) gives the following data: top of Mississippian, 550 feet; top of Ordovician, 575 feet; total depth, 2,300 feet.

This well penetrated foreland facies rocks west of the Ouachita front.

X-ray data.—None.

References.—Sellards (1933, p. 197).
Bureau of Economic Geology files.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Caldwell.

Well name.—Gulf Coast Drilling Company No. 1 Schawe.

Location.—Thomas Maxwell survey.

Elevation.—604 feet. *Total depth.*—3,445 feet. *Completed.*—Before 1932.

Top of metamorphic rocks.—3,415 feet. *Elevation of metamorphic rocks.*— –2,811 feet.

Thin section coverage (depth in feet).—None.

Description of metamorphic rocks.—According to Sellards (1931b, 1933), this well penetrated shale. Its location indicates, however, that it encountered highly sheared weakly metamorphosed rocks in the black slate belt of the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1931b, p. 822; 1933, p. 188).

County.—Caldwell.

Well name.—Magnolia Petroleum Company No. 1 Hardeman (salt-water disposal well); also known as United North and South No. 1-A T. C. Gideon.

Location.—M. G. Dykes survey; 900 feet F most W'ly NEL, 1,250 feet F most N'ly NWL.

Elevation.—470 feet, derrick floor. *Total depth.*—4,845 feet. *Completed.*—ni.

Top of metamorphic rocks.—4,810 feet. *Elevation of metamorphic rocks.*— –4,340 feet.

Thin section coverage (depth in feet).—None

Description of metamorphic rocks.—From its location, this well probably penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1957.

County—Caldwell.

Well name.—Magnolia Petroleum Company No. 40 Alf Mercer.

Location.—Nancy Reaville survey; 1,535 feet FSEL, 5,535 feet FSWL; 6 mi. NW of Luling.

Elevation.—487 feet. *Total depth.*—4,720 feet. *Completed.*—1953.

Top of metamorphic rocks.—4,697 feet. *Elevation of metamorphic rocks.*— –4,210 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4710–20.

Description of metamorphic rocks.—The single sample examined is pyritic sericite phyllite veined by dolomite. Metamorphism is low grade with a high shearing element; the rock is well foliated and locally shows development of fracture cleavage.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: R. E. Wills, Magnolia Petroleum Company, 1953.

County.—Caldwell.

Well name.—United North and South Development Company No. 1 Gideon.

Location.—M. G. Dykes survey; 1,300 feet F most N'ly NWL, 1,330 feet FNEL of Caldwell survey.

Elevation.—470 feet. *Total depth.*—5,345 feet. *Completed.*—1929.

Top of metamorphic rocks.—5,335 feet. *Elevation of metamorphic rocks.*— -4,865 feet.

Thin section coverage (depth in feet).—None.

Description of metamorphic rocks.—From its location, this well probably penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: R. E. Wills, Magnolia Petroleum Company, 1953.

County.—Caldwell.

Well name.—United North and South Development Company No. 1 George Kelly.

Location.—Nancy Reaville survey; 525 feet FSWL, 725 feet FSEL.

Elevation.—463 feet. *Total depth.*—7,854 feet. *Completed.*—1928.

Top of metamorphic rocks.—4,750 feet. *Elevation of metamorphic rocks.*— -4,287 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 6900, 7103, 7150 (2), 7240.

Description of metamorphic rocks.—Sellards (1931b) described rocks encountered in this well as "schist." Barnes (*in* Sellards, 1933) reported "green schist with cleavage dipping at 16°." Samples examined for this study are graphitic sericite-chlorite phyllite; some samples contain abundant rutile needles. Locally the foliation shows crumpling, convolution, and micro-thrust faulting. Metamorphism is low grade with a high shearing element.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1948); Goldstein and Reno (1952, p. 2281); Sellards (1931b, p. 822; 1933, p. 133).

Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; R. E. Wills, Magnolia Petroleum Company, 1953.

Core fragments from 6,900 feet are in Bureau of Economic Geology Well Sample Library.

County.—Caldwell.

Well name.—United North and South Development Company No. 8 W. H. Tabor.

Location.—Nancy Reaville survey; 7,550 feet FNEL, 120 feet FSEL.

Elevation.—492 feet. *Total depth.*—4,852 feet. *Completed.*—1927.

Top of metamorphic rocks.—4,796 feet. *Elevation of metamorphic rocks.*— -4,304 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4822, 4831, depth unknown.

Description of metamorphic rocks.—Bailey (*in* Sellards, 1933, p. 132) described samples from this well as calcite-quartz-sericite schist containing pink garnets. Samples examined in this study are sericite phyllite veined with carbonate and showing well-developed fracture cleavage; foliation is sharply wrinkled between cleavage planes and locally there is micro-thrust faulting. Carbonate veinlets are severely strained and show a herringbone structure. Metamorphism is low grade with a strong shearing element.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1948); Goldstein and Reno (1952, p. 2284); Sellards (1931b, p. 822; 1933, pp. 132–133).

Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; R. E. Wills, Magnolia Petroleum Company, 1953.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Caldwell.

Well name.—United North and South Development Company No. 2 Tiller (also known as No. 1 Tiller).[40]

[40] Apparently there has been some confusion in marking samples; the No. 1 and No. 2 are most probably the same well.

Location.—John Henry survey; 7,300 feet FNEL, 5,550 feet FSEL.

Elevation.—438 feet. *Total depth.*—7,499 feet. *Completed.*—1928.

Top of metamorphic rocks.—4,808 feet. *Elevation of metamorphic rocks.*— -4,370 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 5957–58. BUREAU OF ECONOMIC GEOLOGY: 6696 (2), 7169–71, 7483.

Description of metamorphic rocks.—Barnes (*in* Sellards, 1933, p. 133) described this rock as sericite-chlorite schist with the schistosity dipping at 15° in the core and bedding crossing the schistosity at a high and irregular angle. Samples examined for this study are graphitic sericite-chlorite phyllite; in some sections the mica is muscovite rather than sericite; tiny needles of rutile are abundant, and in one thin section albite makes up a substantial portion of the rock. Foliation is commonly wavy and fracture cleavage is locally developed; rucking and herringbone structures occur between closely spaced cleavage planes. Metamorphism is low grade with a high shearing element.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1948); Sellards (1931b, p. 822; 1933, pp. 132–133).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; R. E. Wills, Magnolia Petroleum Company, 1953.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Caldwell.

Well name.—J. S. Woodward, Incorporated, No. 1 P. S. King.

Location.—Sampson Connell survey; 2,000 feet FEL, 2,650 feet FSEL; 2 mi. S of Lytton Springs.

Elevation.—595 feet, derrick floor. *Total depth.*—4,516(?) feet. *Completed.*—1955.

Top of metamorphic rocks.—4,430 feet. *Elevation of metamorphic rocks.*— -3,835 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4440–50, 4500–10.

Description of metamorphic rocks.—The sequence is composed of rutiliferous hematitic chlorite-sericite phyllite and phyllitic metaquartzite veined with massive quartz, locally containing vermicular chlorite, and carbonaceous (graphitic?) dolomitic sericitic and chloritic metaquartzite containing chert grains and showing a relict clastic fabric. Metamorphism is low grade with a high shearing element; grain stretching is pronounced in the metaquartzites.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957; J. R. Sandidge, Magnolia Petroleum Company, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Caldwell.

Well name.—J. S. Woodward, Incorporated, No. 1 Taylor.

Location.—J. P. Bell survey; 1,850 feet F most N'ly NWL, 6,050 feet F most W'ly SWL; 4 mi. NW of Lockhart.

Elevation.—483 feet. *Total depth.*—4,239 feet. *Completed.*—1955.

Top of metamorphic rocks.—4,205 feet. *Elevation of metamorphic rocks.*— -3,722 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4190–4200, 4220–30.

Description of metamorphic rocks.—The samples examined are chlorite-sericite phyllite, locally graphitic and locally containing abundant rutile needles. Metamorphism is low grade with a strong shearing element.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957; J. R. Sandidge, Magnolia Petroleum Company, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Collin.

Well name.—Deep Rock Oil Corporation No. 1 W. M. Sherley.

Location.—D. Van Winkle survey; 3,500 feet FSL, 5,385 feet FEL; 3 mi. S of Westminster.

Elevation.—586 feet. *Total depth.*—8,887 feet. *Completed.*—1952.

Top of Paleozoic rocks.—3,932 feet. *Elevation of Paleozoic rocks.*— -3,346 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 3950–60, 3980–90 (2), 4010–20, 4020–30, 4100–10, 4170–80, 4320–30, 4360–80, 4480–90, 5420–30, 5980–90, 5990–00, 6550–60, 6560–70, 6570–80, 6690–00, 6820–30, 6880–90, 7050–60, 7650–60, 7660–70, 7680–90, 7690–00, 7710–20.

Description of Paleozoic rocks.—Goldstein (1959) reported base of Cretaceous and top of Bigfork, 3,932 feet; top of Womble, 4,385 feet; and total depth 8,887 feet, in lower Womble. According to Morgan (1955) this well may have passed through a thrust fault into Strawn beds. Hazzard (1958) called attention to steep dips.

Three units can be recognized in the Paleozoic section in this well: (1) dark chert containing abundant organic material overlying dark shale (Bigfork-Womble section), (2) fine-grained quartzitic sandstone, and (3) fine-grained fossiliferous sandy dolomitic limestone. Quartz veins carrying bituminous material are common in the upper dark chert-shale section. The lower two units, beginning at about 5,400 feet, may be Mississippian-Pennsylvanian rocks of foreland facies, or they may be Womble (Goldstein, 1959).

This well penetrated unmetamorphosed lower Paleozoic Ouachita facies rocks in the frontal zone of the Ouachita belt and possibly passed through a thrust fault into younger beds of foreland facies.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955, 1959; R. T. Hazzard, Gulf Oil Corporation, 1958; H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—Collin.

Well name.—Humble Oil & Refining Company No. 1 H. C. Miller.

Location.—L. Searcy survey; 110 feet FNL, 840 feet FWL; 3½ mi. W of McKinney.

Elevation.—603 feet, derrick floor; 591 feet, ground. *Total depth.*—11,407 feet. *Completed.*—1954.

Top of Paleozoic rocks.—3,051 feet. *Elevation of Paleozoic rocks.*— –2,448 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3600–10, 3870–80, 4250–60, 5560–70, 6240–50, 7100–10, 7600–10, 8000–10, 8450–60, 9000–10, 10,729, 10,743, 10,778, 10,806, 10,834, 10,865, 10,870.

Description of Paleozoic rocks.—The following tops are reported by Shelby (1958): top of Paleozoic (Strawn), 3,051 feet; top of Ordovician, 9,152 feet; he noted that older Pennsylvanian rocks probably are present between known Strawn beds and the top of the Ordovician sequence. According to Barnes (1959), this well encountered Ellenburger rocks at 9,152 feet; for a description of this section (9,152 feet to total depth), see Barnes (1959). The well penetrated a body of basaltic rock within the Ellenburger section which is probably a sill.

The sequence overlying the Ellenburger rocks in this well consists of interbedded dark gray shale and sandstone with thin limestone beds. The sandstones are mostly gray, fine- to medium-grained, rarely coarse-grained, subangular to subround, fairly well-sorted, cherty quartz sandstone, commonly calcareous, locally argillaceous, micaceous, dolomitic, quartzitic, slightly feldspathic, and commonly containing abundant grains of shale and chert (dark cryptocrystalline chert, commonly dolomitic, spiculitic, rich in dark organic material—Ouachita type; probably Arkansas novaculite or Bigfork chert) as well as sporadic large grains of both quartz and chert. Shales are dark gray, silty and sandy. Limestones are mostly fine-grained silty and sandy fossiliferous calcilutite. The sequence is identified as Strawn-Atoka.

This well penetrated foreland basin rocks west of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1959, p. 369).
Personal communication: T. H. Shelby, Jr., Humble Oil & Refining Company, 1958.

County.—Collin.

Well name.—Pure Oil Company No. 1 Finley.

Location.—Martha Herron survey; center of Finley 290-acre tract.

Elevation.—707 feet. *Total depth.*—6,000 feet. *Completed.*—1944.

Top of Paleoozic rocks.—2,850 feet. *Elevation of Paleozoic rocks.*— –2,143 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—The following stratigraphic data are reported by Goldstein (1955): base of Cretaceous and top of Pennsylvanian (Strawn), 2,850 feet; top of Ellenburger, 5,510 feet; total depth 6,000 feet, in Ellenburger. This well penetrated foreland rocks west of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; H. J. Morgan, Jr., The Atlantic Refining Company, 1957.

County.—Collin.

Well name.—Pure Oil Company No. 1 Light.

Location.—J. Ragsdale survey.

Elevation.—641 feet. *Total depth.*—5,966 feet. *Completed.*—1944.

Top of Paleozoic rocks.—2,510 feet. *Elevation of Paleozoic rocks.*— -1,869 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4030–40 (5), 4100–10 (4), 4200–10 (3), 4300–10 (2), 4400–10 (2), 4600–10, 4840–50 (3), 4900–10 (4), 5400–10, 5500–10, 5600–10 (2), 5960–66 (2).

Description of Paleozoic rocks.—Goldstein (1955) reported top of Pennsylvanian (Strawn), 2,510 feet; top of Ellenburger, 4,110 feet; total depth, 5,966 feet, in Ellenburger. Thin section examination shows a sequence of dark silty shale overlying fine-grained dolomitic limestone, more or less fossiliferous. The rocks are normal foreland rocks west of the Ouachita structural belt.

X-ray data.—$I > ML > Ch > K$; $10/7 \sim 1.4$; $F = 20$; $SR = 1.51$. Shales are composed of mixed layer illite-montmorillonite with minor kaolinite characteristic of foreland shales.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Comal.

Well name.—Roland Blumberg No. 1 D. C. Knibbe.

Location.—John M. Christian survey; 330 feet FWL, 330 feet FSL; 7½ mi. SE of Kendalia.

Elevation.—1,075 feet (from topographic map). *Total depth.*—3,105 feet. *Completed.*—1958.

Top of Paleozoic rocks.—540 feet. *Elevation of Paleozoic rocks.*— +535 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 525–30, 545–50, 685–90 (3), 1340–45, 1535–40, 1800–20, 1895–00, 2015–20, 2175, 2705 (2), 2930.

Description of Paleozoic rocks.—The Paleozoic sequence in this well indicates structural complexity. The upper unit is composed of dark sericite-chlorite clay-slate, locally pyritic, silty, and siliceous; dark chloritic micaceous metasiltstone; and dark, fine-grained, angular, very poorly sorted, micaceous chloritic feldspathic quartz sandstone. Underlying this unit is a sequence of dark cryptocrystalline dolomitic chert and dark red-brown argillaceous chert or siliceous shale rich in brown organic material and containing small (0.05 mm) round siliceous bodies (radiolarians?); the cherts are fractured and fractures are filled with vein quartz. Beneath the siliceous rocks is a sequence of dark sandy chloritic micaceous feldspathic quartz siltstone and dark chloritic micaceous metashale or clay-slate, locally strongly deformed. The deepest unit penetrated is a fine-grained, subangular to subround, poorly to fairly well sorted, slightly feldspathic to feldspathic argillaceous quartz sandstone.

Metamorphism ranges from incipient to weak and is higher in the upper unit; structures are foliation and contortion (in clay-slates and metashales) and fracturing (in the cherts). The deepest unit is not metamorphosed.

The incipiently to weakly metamorphosed upper clastic unit is probably Mississippian-Pennsylvanian; possibly it is correlative with the Stanley but the lithology is not typically Stanley. The chert-siliceous shale sequence below has characteristics of both Arkansas novaculite and Bigfork chert. Goldstein (1958) reported the following tentative identifications: 525 to 530 feet, probably Mississippian-Pennsylvanian; 685 to 690 feet, closely resembles upper Arkansas novaculite; 1,340 to 1,350 feet, closely resembles Blaylock sandstone; 1,535 to 1,540 feet, either lower middle member of Arkansas novaculite or Bigfork, probably the latter.

The chert-siliceous shale sequence is very similar to that seen in the No. 2 Slayden and No. 1 Bailey wells in Bell County. The siltstone-metashale sequence beneath the siliceous rocks is tentatively identified as Womble; it shows incipient metamorphism. Underlying the Womble(?) is an unmetamorphosed quartz sandstone of Mississippian-Pennsylvanian type. This rock cannot be positively identified as Ouachita facies (Stanley) or foreland facies (Atoka); if it is foreland facies (Atoka) a major frontal displacement is indicated in this area; if it is Ouachita facies it merely indicates overthrusting or reverse faulting in the frontal zone of the Ouachita belt with lower Paleozoic Ouachita rocks thrust over Stanley.

This well penetrated incipiently to weakly metamorphosed upper and lower Paleozoic Ouachita facies rocks, intersected a thrust fault, and passed into Mississippian-Pennsylvanian sandstone (foreland facies?). It is located in the frontal zone of the Ouachita belt south of the Llano uplift.

X-ray data.—None.

References.—Personal communication: Roland Blumberg, 1957; August Goldstein, Jr., Bell Oil and Gas Company, 1958; J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Comal.

Well name.—Caldwell & Lanier No. 1 T. J. Byler.

Location.—HE&WT survey; 1,028 feet FNL, 486 feet FWL; extreme N part of County.

Elevation.—1,220 feet (from topographic map). *Total depth.*—948 feet. *Completed.*—1932.

Top of Paleozoic rocks.—615 feet. *Elevation of Paleozoic rocks.*— +605 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 722.

Description of Paleozoic rocks.—The single sample examined for this study is composed of dark green shale or metashale showing incipient metamorphism; possibly this sample is lower Paleozoic Ouachita facies, but a positive identification cannot be made. The well is in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Comal.

Well name.—W. W. Connell, Incorporated, No. 1 Casey.

Location.—HE&WT survey; 2,700 feet FNL, 660 feet FEL.

Elevation.—1,325 feet. *Total depth.*—1,300 feet. *Completed.*—1947.

Top of Paleozoic rocks.—875(?) feet. *Elevation of Paleozoic rocks.*— +450(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Scout card shows "top slate, 875." The well probably penetrated very weakly metamorphosed Ouachita facies rocks (lower Paleozoic?) in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Comal.

Well name.—Oblate Fathers Water Well.

Location.—Guadalupe Herrera survey; 600 feet FSL, 4,500 feet FWL; 1 mi. SSW of Bulverde.

Elevation.—1,300 feet (from topographic map). *Total depth.*—1,300 feet. *Completed.*—1954.

Top of Paleozoic rocks.—900± feet. *Elevation of Paleozoic rocks.*— +400± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Goldstein (1958) reported that a single sample from 1,320 feet is composed of silty clay-slate and argillaceous low-rank metasiltstone.
This well seems to have penetrated very weakly metamorphosed rocks of Ouachita facies (lower Paleozoic?) in the southern part of the frontal zone.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Bell Oil and Gas Company, 1958; Robert Pavlovic, Magnolia Petroleum Company, 1955.

County.—Comal.

Well name.—Yates No. 2 Heidrick.

Location.—A. M. Holbrook survey; 1,800 feet FNWL, 1,850 feet FSWL.

Elevation.—999 feet. *Total depth.*—1,867 feet. *Completed.*—1937.

Top of Paleozoic rocks.—1,822 feet. *Elevation of Paleozoic rocks.*— -823 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—ni.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957; J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Coryell.

Well name.—Buckeye and Mid-Tex Oil Company (Mid-Kansas?) No. 1 G. A. Strickland.

Location.—John Winn survey; 5,000 feet FEL, 4,300 feet FSL; 17 mi. SW of Gatesville.

Elevation.—946(?) feet; 912(?) feet. *Total depth.*—3,628 feet. *Completed.*—1919.

Top of Paleozoic rocks.—615(?) feet. *Elevation of Paleozoic rocks.*— +331(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1050–70, 1494–1520 (2), 1990–2005, 2170–80 (2), 3470–75, 3507–12.

Description of Paleozoic rocks.—Adkins and Arick (1930) reported 1,600 feet of Strawn, 375 feet of Smithwick, 140 feet of Marble Falls, and 13 feet of Ellenburger; they placed top of Ellenburger at 3,615 feet, which is the same figure given by Sellards (1933) as top of Ordovician. Sample descriptions in the files of the Bureau of Economic Geology suggest the following sequence: top of Atoka, 615± feet; top of Marble Falls—Barnett, 3,100± feet; top of Ellenburger, 3,620 feet.

Thin section studies show a sequence of fine-grained, angular to subround, fairly well-sorted, quartz sandstone and dark silty shale of Atoka type overlying siliceous spiculitic limestone identified as Marble Falls. No study of the underlying Ellenburger was made. The rocks are foreland facies, and the well is located west of the Ouachita structural belt.

X-ray data.—I > Ch > ML > K(?); 10/7 ∼ 13; F = 20; SR = 2.1.

References.—Adkins and Arick (1930, pp. 8–10); Sellards (1933, p. 206).
Bureau of Economic Geology files.
Personal communication: Robert Roth, Humble Oil & Refining Company, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Coryell.

Well name.—Cockburn No. 1 Kearny (Kernay, Kearday).

Location.—James Butterworth survey; 330 feet FSL, 1,650 feet FEL; 10 mi. SE of Gatesville.

Elevation.—ni. *Total depth.*—4,520 feet. *Completed.*—1950.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1955–70, 2030–40, 2150–60, 2305–10, 2795–05, 3400–10, 4200–10, 4210–20, 4355–60.

Description of Paleozoic rocks.—Information from sample log shows that the well is in "Strawn" at 1,950 feet with total depth 4,520 feet in "Strawn"; lithology is given as hard gray quartzitic sandstone.

The sequence is composed of dark silty shale and fine-grained, mostly subangular to subround, fairly well-sorted, slightly argillaceous and feldspathic quartz sandstone, locally containing shale and chert fragments. The rocks show no evidence of metamorphism. This section is probably Atoka rather than Strawn. This well penetrated foreland basin rocks west of the Ouachita belt.

X-ray data.—I > ML > Ch > K; 10/7 ∼ 1.8; F = 20.

References.—Personal communication: J. C. Barker, General Crude Oil Company, 1957.

County.—Coryell.

Well name.—Coryell County Oil Corporation No. 1 J. Q. Davidson.

Location.—Neil Robinson survey.

Elevation.—ni. *Total depth.*—4,400± feet. *Completed.*—1933(?).

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in the files of the Bureau of Economic Geology indicate that the well is in Atoka at total depth. The well is west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Coryell.

Well name.—E. A. Dunham (New York Syndicate) No. 1 Tienert.

Location.—Elizabeth Jones survey; 3,000 feet FSL, 3,400 feet FWL.

Elevation.—1,094 feet. *Total depth.*—3,725(?) feet. *Completed.*—1921.

Top of Paleozoic rocks.—800(?) feet. *Elevation of Paleozoic rocks.*— +294(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3467 (2).

Description of Paleozoic rocks.—Adkins and Arick (1930) reported 1,900 feet of Strawn, 430(?) feet of Bend, and 21 feet of Ellenburger with top of Ellenburger at 3,579 feet. Sellards (1933) noted

top of Ordovician at 3,384 feet. The "Strawn" and "Bend" sequence reported by Adkins and Arick is probably Atoka and Marble Falls—Barnett. The single thin section (3467) available for this study is fine-grained Ellenburger dolomite.
This well is in foreland facies rocks west of the Ouachita structural belt.

X-ray data.—None.

References.—Adkins and Arick (1930, pp. 8–10); Barnes (1948); Sellards (1933, p. 206).
Personal communication: Robert Roth, Humble Oil & Refining Company, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Coryell.

Well name.—General Crude Oil Company No. 1 Earnest Day.

Location.—R. T. Davidson survey; 660 feet FSL, 2,550 feet FEL; 5 mi. W of Moody.

Elevation.—732 feet, derrick floor. *Total depth.*—9,275 feet. *Completed.*—1957.

Top of Paleozoic rocks.—1,190 feet. *Elevation of Paleozoic rocks.*— –458 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1340–50, 1400–10, 1500–10, 1620–30, 2590–00, 3550–60, 3620–30, 5700–10, 5741–50, 5880–90, 6360–90, 6530–40, 6600–10, 6700–10, 6750-60, 6770–80, 6800–10, 6870–80, 6990–00, 7300–10, 7380–90, 7700–10, 7740–50 (3), 7990–00 (3), 8650–60, 9200–10.

Description of Paleozoic rocks.—The following divisions are based on sample examination: top of Stanley, 1,190 feet; top of pre-Stanley, 6,800± feet; top of carbonate beds, 7,380 feet; top of sandstone and shale section, 7,405 feet (siliceous shale, 7,530 feet); top of dense limestone and shale, 7,580 feet; top of dark chert and shale, 8,090 feet. Graptolites from 7,540 to 7,550 and 7,560 to 7,570 feet are Bigfork-Womble.
Petrographically, the upper sequence is composed of fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone containing angular garnet in the heavy mineral fraction and dark silty shale—it is typical Stanley. There is a hard green siliceous tuffaceous shale at the base of the Stanley (samples 6,700–6,710, 6,750–6,760, 6,770–6,780 feet) which shows relict vitroclastic fabric. Samples at 6,800 to 6,810 and 6,870 to 6,880 feet are mostly light-colored to dark argillaceous microangular to cryptocrystalline radiolarian cherts, containing dark organic material, sparsely dolomitic, and very dark brown siliceous shale rich in brown organic matter, locally dolomitic; this sequence resembles Arkansas novaculite. The lower section shows characteristic Bigfork lithology—fine-grained argillaceous dolomitic limestone, locally spiculitic, dark siliceous dolomitic shale, and dark argillaceous dolomitic chert, all containing abundant dark organic material. Dark brown slightly micaceous shale and micaceous chloritic quartz siltstone in the last two samples thin sectioned (8650–60 and 9200–10) are probably Womble. Maner (1958) believed that this well intersected a thrust and passed into Atoka beds at about 9,000 feet.
These rocks are unmetamorphosed to incipiently metamorphosed Ouachita facies rocks of both upper and lower Paleozoic age; except in the cherts, there is a lack of the quartz and calcite veinlets which characterize similar rocks elsewhere.
This well penetrated the frontal zone of the Ouachita structural belt.

X-ray data.—$I > Ch > ML$; $10/7 \sim 1$; $F = 20$; $SR = 2.15$.

References.—Personal communication: J. C. Barker, General Crude Oil Company, 1957; W.B.N. Berry, University of Houston, 1957; R. P. Maner, Shell Oil Company, 1958.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Coryell.

Well name.—Kansas City Syndicate No. 2 Thomas Young.

Location.—Thomas Young survey; 4.8 mi. N of Killeen.

Elevation.—838 feet (by aneroid barometer). *Total depth.*—2,985 feet. *Completed.*—1920.

Top of Paleozoic rocks.—665± feet. *Elevation of Paleozoic rocks.*— +173± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1008, 1785, 1955, 2340, 2790.

Description of Paleozoic rocks.—Notes in the Bureau of Economic Geology files indicate that the well bottomed in Atoka.
The sequence consists of: (1) fine-grained, angular to subround, fairly well-sorted to poorly sorted, calcareous quartz sandstone, commonly argillaceous, silty, locally quartzitic; (2) dark silty shale; (3) angular argillaceous quartz siltstone; and (4) dark fine-grained fossiliferous limestone containing angular quartz silt-sand.
This well penetrated Atoka beds west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Coryell.

Well name.—Keystone Texas Oil Company No. 1 J. S. Clark.

Location.—G. W. Carlile survey; 10 mi. SW of Gatesville.

Elevation.—ni. *Total depth.*—3,630 feet. *Completed.*—1919.

Top of Paleozoic rocks.—695± feet. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Descriptions of samples in the files of the Bureau of Economic Geology suggest the following sequence: top of Paleozoic (Atoka), 695 feet; top of Marble Falls—Barnett, 3,311 feet; top of Ellenburger, 3,665 feet. This well penetrated foreland basin rocks west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Coryell.

Well name.—New York Syndicate No. 1 Charles Gotcher.

Location.—W. T. Whitely survey; 4 mi. SW of Copperas Cove.

Elevation.—1,130 feet. *Total depth.*—3,192 feet. *Completed.*—1919.

Top of Paleozoic rocks.—620± feet. *Elevation of Paleozoic rocks.*— +510± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2900.

Description of Paleozoic rocks.—Adkins and Arick (1930) reported 1,700 feet of Strawn, 125 feet of Bend, and 57 feet of Ellenburger; top of Ellenburger is given as 3,035 feet. Sellards (1933) reported top of Ordovician at 3,025 feet. According to Goldstein (1955), this well was in Marble Falls or Barnett at 2,900 feet. Sample descriptions in the files of the Bureau of Economic Geology suggest the following sequence: top of Atoka, 620 feet; top of Marble Falls—Barnett, 2,892 feet; top of Ellenburger, 3,043 feet.

The single sample studied from 2,900 feet is a black spiculiferous pyritic calcareous shale, probably Marble Falls.

This well penetrated foreland rocks west of the Ouachita structural belt.

X-ray data.—None.

References.—Adkins and Arick (1930, pp. 8–10); Barnes (1948); Sellards (1933, p. 206).
Bureau of Economic Geology files.
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; Robert Roth, Humble Oil & Refining Company, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Coryell.

Additional wells not shown on map (Pl. 2) and not studied because of lack of samples or basic data:

U. S. ARMY WATER WELL NO. 1—
Location: Gatesville area. *Total depth:* 760 feet. *Top of Paleozoic rocks:* 748 feet. Dark gray compact clay and hard quartzitic cherty sandstone.

U. S. ARMY WATER WELL NO. 2—
Location: Gatesville area. *Total depth:* 688 feet. *Completed:* 1943. *Top of Paleozoic rocks:* 674± feet. Blue gray shale.

U. S. ARMY WATER WELL NO. 3—
Location: Gatesville area. *Total depth:* 721 feet. *Top of Paleozoic rocks:* 700 feet. Black hard brittle shale.

U. S. ARMY WATER WELL NO. 6—
Location: Gatesville area. *Total depth:* 735 feet. *Top of Paleozoic rocks:* 730 feet. Yellow-red clay—old soil?

U. S. ARMY WATER WELL NO. 7—
Location: Gatesville area. *Total depth:* 745 feet. *Top of Paleozoic rocks:* 740 feet. Green-gray clay.

U. S. ARMY WATER WELL NO. 10—
Location: Gatesville area. *Total depth:* 764 feet. *Completed:* 1943. *Top of Paleozoic rocks:* 762 feet. Dark maroon and red silty clay.

U. S. ARMY WATER WELL NO. 11—
Location: North Camp Hood. *Total depth:* 755 feet. *Completed:* 1943. *Top of Paleozoic rocks:* 735 feet. Dark fine-grained hard quartzitic sandstone.

U. S. ARMY WATER WELL NO. 12—
Location: North Camp Hood. *Total depth:* 755 feet. *Completed:* 1943. *Top of Paleozoic rocks:* 730 feet. Dark gray almost black hard cherty quartzitic sandstone.

SUMMARY OF ARMY WELLS—
The above wells apparently penetrated a weathered zone at the top of the Atoka formation and underlying Atoka sandstone and shale.

R. T. ELLIOTT WELL—
Location: 3½ mi. NW of Copperas Cove. *Total depth:* 1,875(?) feet. *Completed:* 1919. *Top of Paleozoic rocks:* 500(?) feet. Driller's log suggests Atoka lithology; well is ½ mi. E of Dunham No. 1 Tienert (p. 245).

COLUMBIA TEXAS OIL COMPANY NO. 1 W. L. SADLER—
Location: 19 mi. S of Gatesville. *Elevation:* 900± feet. *Total depth:* 4,360 feet. *Completed:* 1920. Driller's log suggests total depth in Atoka.

County.—Dallas.

Well name.—City of Dallas No. 45 Water Well.

Location.—NE corner of Hillcrest Avenue and Walnut Lane, Dallas, Texas.

Elevation.—640 feet. *Total depth.*—3,058 feet. *Completed.*—1956.

Top of Paleozoic rocks.—3,039 feet. *Elevation of Paleozoic rocks.*— -2,399 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3037–42, 3042–47.

Description of Paleozoic rocks.—The rocks are composed of very dark gray to red silty and sandy shale and dark, fine-grained, angular to round, poorly sorted, argillaceous micaceous feldspathic quartz sandstone containing angular garnet in the heavy mineral fraction; the rocks are cut by calcite veinlets.

Sample coverage on this well is poor. The lithology appears to be Stanley type; the well probably entered the frontal zone of the Ouachita structural belt.

X-ray data.—None.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1958.

County.—Dallas.

Well name.—City of Dallas No. 46 Water Well.

Location.—1¼ mi. N of Carrollton; 1¼ mi. N, ¼ mi. W of intersection of the old Denton and Beltline roads.

Elevation.—ni. *Total depth.*—2,321 feet. *Completed.*—1957.

Top of Paleozoic rocks.—2,260 feet. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2260–70, 2300–10.

Description of Paleozoic rocks.—The rocks penetrated in this well are dark silty shale, locally micaceous, locally dolomitic. The facies cannot be identified with certainty.

X-ray data.—$ML > I > K > Ch$; $10/7 \sim 0.8$; $SR = 1.0$. Abundant ML with high montmorillonite content suggests foreland facies.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1958.

County.—Dallas.

Well name.—Garland City Water Well (J. L. Myers & Sons, Federal Works Agency Docket).

Location.—J. W. Keen survey, W/2 section 25; 1 mi. W of Garland.

Elevation.—550± feet. *Total depth.*—3,629 feet. *Completed.*—1943.

Top of Paleozoic rocks.—3,570 feet. *Elevation of Paleozoic rocks.*— -3020± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Top of Paleozoic by electric log is 3,570 feet.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Dallas.

Well name.—Lacey and Guiberson No. 1 Meyers (Moyer?).

Location.—Thomas Johnson survey; 660 feet FNEL, 1,980 feet FSWL; 17 mi. SE of Dallas.

Elevation.—366 feet. *Total depth.*—4,843 feet. *Completed.*—1943.

Top of Paleozoic rocks.—4,440 feet. *Elevation of Paleozoic rocks.*— -4,074 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 4370–84, 4468–84, 4484–00, 4523–39, 4616–32. SHELL OIL COMPANY: 4455.

Description of Paleozoic rocks.—According to Goldstein (1955), base of Cotton Valley and top of Paleozoic rocks, Stanley(?), is 4,440 feet, and total depth is 4,843 feet in Stanley(?). Thin section study shows a sequence composed mostly of micaceous chloritic argillaceous siltstone veined with quartz and quartz-calcite. The rocks are Ouachita facies; on general lithology and location, the sequence is probably Stanley.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Dallas.

Well name.—McNeil & Mathews No. 1 W. W. Seaton.

Location.—J. G. Garrett survey; 400 feet FEL, 1,900 feet F most S'ly line; 2 mi. N of Britton.

Elevation.—755± feet. *Total depth.*—2,660 feet. *Completed.*—1928.

Top of Paleozoic rocks.—2,197(?) feet; 2,090(?) feet. *Elevation of Paleozoic rocks.*— -1,442(?) feet; -1,335(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2240, 2300, 2400, 2435, 2485, 2655.

Description of Paleozoic rocks.—A driller's log in Bureau of Economic Geology files indicates top of Paleozoic rocks at about 2,090± feet; cores at 2,435 and 2,655 feet are described as black slickensided shale and hard black shale. Sellards (1933) gave approximate top of Paleozoic rocks as 2,435 feet and described the rock as "black shale." Thin section studies show the entire sequence penetrated is dark gray silty shale; no quartz or calcite veins were noted. In all probability these rocks are Atoka.

This well penetrated foreland rocks west of the Ouachita structural belt.

X-ray data.—$I > ML > Ch > K$; $10/7 \sim 1.1$; $F = 20$; $SR = 1.55$. Shales show a mixed layer illite-montmorillonite mineralogy of Atoka type.

References.—Sellards (1933, p. 188).
Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1955.
Samples (incomplete) are in Bureau of Economic Geology Well Sample Library.

County.—Dallas.

Well name.—Magnolia Petroleum Company No. 1 Trigg.

Location.—T. W. Cousey survey; 660 feet N, 660 feet E of NE cor. of SA&MG survey.

Elevation.—526 feet, derrick floor. *Total depth.*—10,231 feet. *Completed.*—1955.

Top of Paleozoic rocks.—2,043 feet. *Elevation of Paleozoic rocks.*— -1,517 feet.

Thin section coverage (depth in feet). —None.

Description of Paleozoic rocks.—H. A. Sellin (1957) reported base of Cretaceous and top of Pennsylvanian(?), 2,043 feet; top of Strawn, 3,173 feet; top of Atoka(?), 5,485 feet; top of Marble Falls, 8,055 feet; top of Barnett(?), 8,658 feet; top of Viola, 9,057 feet; top of Simpson, 9,357 feet; top of Ellenburger, 9,742 feet; total depth in Ellenburger.

This well penetrated foreland basin rocks west of the Ouachita structural belt.

X-ray data.—None.

References.—Personal communication: H. A. Sellin, Magnolia Petroleum Company, 1957.

County.—Dallas.

Well name.—Mark Raley No. 1 Morris.

Location.—C. Gibbs survey; 129 feet FNL, 1,483 feet FWL; 2 mi. S of Grand Prairie.

Elevation.—488 feet. *Total depth.*—2,636 feet. *Completed.*—ni.

Top of Paleozoic rocks.—2,000± feet. *Elevation of Paleozoic rocks.*— -1,512± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—From its location, this well probably penetrated Atoka rocks west of the Ouachita belt.

X-ray data.—None.

References.—None.

County.—Dallas.

Well name.—Texas Water Wells, Incorporated, No. 40 City of Dallas.

Location.—J. Nealy Bryan survey; 310 Cadiz Street, Dallas, Texas.

Elevation.—400 feet. *Total depth.*—2,800 feet. *Completed.*—1953.

Top of Paleozoic rocks.—2,790 feet. *Elevation of Paleozoic rocks.*— –2,390 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2790.

Description of Paleozoic rocks.—The single sample examined for this study is red and gray silty shale, locally dolomitic. No reliable determination of facies can be made from this sample. The well is located close to the projected course of the Ouachita front and may be in foreland rocks or within the frontal zone of the structural belt.

X-ray data.—None.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—Dallas.

Well name.—Texas Water Wells, Incorporated, No. 41 City of Dallas.

Location.—Beltline Road, Dallas, Texas.

Elevation.—407 feet. *Total depth.*—3,075 feet. *Completed.*—1952.

Top of Paleozoic rocks.—3,066 feet. *Elevation of Paleozoic rocks.*— –2,659 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—ni.

X-ray data.—None.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—Dallas.

Well name.—Texas Water Wells, Incorporated, No. 42 City of Dallas.

Location.—2700 Singleton Boulevard, Dallas, Texas.

Elevation.—422 feet. *Total depth.*—2,563 feet. *Completed.*—1952.

Top of Paleozoic rocks.—2,530 feet. *Elevation of Paleozoic rocks.*— –2,108 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—ni.

X-ray data.—None.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—Edwards.

Well name.—Humble Oil & Refining Company No. 1 Collins.

Location.—Section 73, block 13, GC&SF survey; 1,980 feet FSL, 1,980 feet FWL; 10 mi. S of Rocksprings.

Elevation.—2,274 feet, derrick floor. *Total depth.*—7,861 feet. *Completed.*—1953.

Top of Paleozoic rocks.—1,500 feet. *Elevation of Paleozoic rocks.*— +774 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—The following stratigraphic data are reported: top of Paleozoic, 1,500 feet; top of Marble Falls, 7,700 feet; top of Simpson, 7,782 feet; top of Ellenburger, 7,810 feet. This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. C. Meacham, Humble Oil & Refining Company, 1957.

County.—Edwards.

Well name.—Hunt Oil Company No. 1 Allison.

Location.—Section 1, block DA 6, GC&SF survey; 330 feet FSL, 330 feet FEL; 18 mi. SE of Rocksprings.

Elevation.—1,903 feet. *Total depth.*—6,510 feet. *Completed.*—1948.

Top of Paleozoic rocks.—1,070 feet. *Elevation of Paleozoic rocks.*— +833 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Goldstein (1955) reported first sample in Trinity at 930 to 940 feet; second sample in Paleozoic rocks at 1,300 feet; base of Smithwick and top of Marble Falls(?), 5,320 feet; top of Ellenburger, 5,460 feet; total depth 6,512 feet, in Ellenburger.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. E. Galley, Shell Oil Company, 1956; August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Edwards.

Well name.—Phillips Petroleum Company No. 1-A Carson.

Location.—Solomon Page survey; 9,500 feet FSWL, 1,320 feet FNWL; 6 mi. WSW of Barksdale.

Elevation.—1,684 feet, derrick floor. *Total depth.*—9,970 feet. *Completed.*—1954.

Top of Paleozoic rocks.—1,090 feet. *Elevation of Paleozoic rocks.*— +594 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Young (1957) reported top of Wolfcamp, 1,090 feet; top of Pennsylvanian, 3,140 feet; top of Simpson, 9,500 feet; top of Ellenburger, 9,657 feet; total depth 9,970 feet, in Ellenburger. Galley (1957) stated that base of Wolfcamp is in the interval 2,600 to 3,200 feet.

This well penetrated foreland basin rocks north of the Ouachita structural belt.

X-ray data.—None.

References.—Personal communication: J. E. Galley, Shell Oil Company, 1957; Addison Young, Phillips Petroleum Company, 1957.

County.—Edwards.

Well name.—Shell Oil Company No. 1 Honeycutt.

Location.—Section 7, TCRR survey; 669 feet FEL, 1,997 feet FSL; 12 mi. W and 3 mi. N of Rocksprings.

Elevation.—2,200 feet, derrick floor. *Total depth.*—8,931 feet. *Completed.*—1945.

Top of Paleozoic rocks.—1,120 feet. *Elevation of Paleozoic rocks.*— +1,080 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1168–75, 1202–08, 1350–60, 2150–60, 3050–60, 4050–60, 5150–60, 7150–60.

Description of Paleozoic rocks.—R. E. Farmer (1959) reported base of Cretaceous, 1,120 feet; top of Ellenburger, 7,220 feet; top of Cambrian sandstone, 8,890 feet. The sequence between the base of Cretaceous and top of Ellenburger is described as gray shale and siliceous sandstone with a few thin beds of fossiliferous limestone toward the bottom. Possibly the bottom part of this sequence is Atoka.

Petrographic study shows that the sequence from base of Cretaceous to top of Ellenburger is composed of (1) dark silty shale, locally micaceous; (2) fine-grained, angular to subround, poorly sorted to fairly well-sorted quartz sandstone ranging from argillaceous to calcareous or dolomitic to siliceous (quartzitic); the sandstone contains shale and chert grains, feldspar content is low; and (3) fine-grained, angular and subangular, argillaceous calcareous and dolomitic quartz siltstone.

The rocks are foreland facies—the well is located north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: R. E. Farmer, Shell Oil Company, 1959.

County.—Ellis.

Well name.—American Liberty Oil Company No. 1 McClain.

Location.—Section 8, R. Pena survey; 4 mi. NE of Palmer.

Elevation.—402 feet. *Total depth.*—4,270 feet. *Completed.*—1954.

Top of Paleozoic rocks.—4,200 feet. *Elevation of Paleozoic rocks.*— -3,798 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—On the basis of location, this well probably encountered the Stanley formation in the frontal zone of the Ouachita structural belt.

X-ray data.—None.

References.—None.

County.—Ellis.

Well name.—Bechner (Dallas Oil Company, United Petroleum Company) No. 1 Howard Garvin.

Location.—Coleman Jenkins survey; 3 mi. SE of Midlothian.

Elevation.—750± feet. *Total depth.*—5,220 feet. *Completed.*—1925(?).

Top of Paleozoic rocks.—2,598(?) feet. *Elevation of Paleozoic rocks.* -1,848(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—The only available information is a driller's log in the files of the Bureau of Economic Geology. Interpretations therefrom indicate that this well penetrated a sequence of black shale and gray to brown sandstone, probably Stanley, in the frontal zone of the Ouachita structural belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Ellis.

Well name.—Hickey and White No. 2 Medford.

Location.—Isaac Carroll survey; 2,300 feet FSWL, 1,980 feet FSEL; 3 mi. S of Maypearl.

Elevation.—506 feet. *Total depth.*—2,312 feet. *Completed.*—1954.

Top of Paleozoic rocks.—2,193(?) feet. *Elevation of Paleozoic rocks.*— -1,687(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—On the basis of location, it is believed that this well probably encountered the Stanley formation in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1956.

County.—Ellis.

Well name.—Lesco (Lasco?) No. 1 Lesage (water well).

Location.—E. D. Harrison survey; 330 feet FNEL, 330 feet FSEL; 3 mi. NW of Italy.

Elevation.—722 feet. *Total depth.*—2,912 feet. *Completed.*—1944.

Top of Paleozoic rocks.—2,520 feet. *Elevation of Paleozoic rocks.*— -1,798 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 2600–10, 2620–30. BUREAU OF ECONOMIC GEOLOGY: 2520–30, 2720–30 (2).

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Paleozoic, 2,520 feet; total depth in Paleozoic (Stanley?). Thin section study shows that the sequence is fine-grained, poorly sorted, argillaceous feldspathic quartz sandstone and dark shale, locally carbonaceous—a typical Stanley lithology.

This well penetrated Stanley in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; H. J. Morgan, Jr., The Atlantic Refining Company, 1956.

Samples in Bureau of Economic Geology Well Sample Library.

County.—Ellis.

Well name.—John Mitchell No. 1 J. L. Rush.

Location.—J. Chambles survey; 330 feet FNL, 800 feet FWL of J. L. Rush tract; 2 mi. W of Midlothian.

Elevation.—662 feet L&S. *Total depth.*—4,061 feet. *Completed.*—1953.

Top of Paleozoic rocks.—2,098 feet. *Elevation of Paleozoic rocks.*— -1,436 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2330–60, 2410–50, 2710–40 (2), 3250–80, 3780–20, 3910–40, 4030–60.

Description of Paleozoic rocks.—The following data are reported by Morgan (1956): top of Paleozoic, 2,080 feet; top of Arkansas novaculite, 2,098 feet; top of Missouri Mountain, 2,416 feet; top of Polk Creek, 3,793 feet; top of Bigfork, 3,846 feet.

Petrographic study shows the following sequence (from top to bottom): (1) light-colored cryptocrystalline to chalcedonic argillaceous chert, locally containing organic matter and veined with quartz (Arkansas novaculite); (2) dark red to opaque hematitic shale, locally silty, and green shale, locally pyritic with sporadic carbonate grains (dolomite?, siderite?) (Missouri Mountain shale); (3) black pyritic bituminous rock (Polk Creek shale?); and (4) dark cryptocrystalline to microgranular chert containing masses of dark organic material, locally dolomitic, locally pyritic, veined with quartz, carbonate, and bitumen; some fragments intensely shattered (Bigfork chert).

Hazzard (1958) reported dips of 45° to 60° in this sequence.

This well penetrated lower Paleozoic Ouachita facies rocks in the frontal zone of the Ouachita belt, probably close to the orogenic front; it is close to wells penetrating foreland rocks (Atoka) in the subcrop and their proximity suggests overthrusting in this area (Pl. 2).

X-ray data.—I > Ch > ML > K; 10/7 ∼ 1.0; SR = 1.9.

References.—Personal communication: R. T. Hazzard, Gulf Oil Corporation, 1958; H. J. Morgan, Jr., The Atlantic Refining Company, 1956.

County.—Ellis.

Well name.—J. B. Stoddard No. 1 W. E. Smith.

Location.—J. B. Edwards survey; 660 feet FNWL, 1,550 feet FSWL.

Elevation.—480 feet. *Total depth.*—5,020 feet. *Completed.*—1942.

Top of Paleozoic rocks.—4,847 feet. *Elevation of Paleozoic rocks.*— -4,367 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4909–10 (3), 4960–70 (2), 5000–10 (2).

Description of Paleozoic rocks.—This well encountered fine-grained, angular, poorly sorted, feldspathic quartz sandstone and gray and red silty shale; the rocks are cut by quartz-calcite veins. The sequence is Stanley.

The well penetrated the frontal zone of the Ouachita belt.

X-ray data.—I > Ch > K; 10/7 ∼ 2.5; SR = 2.3. (Kaolinite occurs only in 4,909 to 4,910-foot sample.) The shales are of Ouachita type and show good crystallinity without mixed layering of illite-montmorillonite typical of the foreland; chlorite content is low.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—Ellis.

Well name.—Triangle Corporation No. 1 Hale.

Location.—Benj. Smith survey; 1 mi. SE of Avalon.

Elevation.—455 feet. *Total depth.*—3,190 feet. *Completed.*—1930.

Top of Paleozoic rocks.—3,060(?) feet. *Elevation of Paleozoic rocks.*— -2,605(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3155–70 (2).

Description of Paleozoic rocks.—Sellards (1931b, 1933) described cores at 3,060 and 3,155 to 3,190 feet as slickensided shale and quartzitic sandstone, probably Stanley-Jackfork. The single core sample examined for this study is composed of fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone of Stanley type. The well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1931b, p. 822; 1933, p. 188).

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Falls.

Well name.—Humble Oil & Refining Company No. 1 Carroll.

Location.—L. Stephens survey; 330 feet FNWL, 1,275 feet FSWL; 5.1 mi. SE of Westphalia.

Elevation.—502 feet. *Total depth.*—3,717 feet. *Completed.*—1951.

Top of metamorphic rocks.—3,610 feet. *Elevation of metamorphic rocks.*— -3,108 feet.

Thin section coverage (depth in feet).—None.

Description of metamorphic rocks.—Goldstein (Goldstein and Reno, 1952) described a thin section of a core (3,614 feet) as a metamorphosed, sheared argillaceous sandstone of Ouachita facies. The general location of the well indicates that it penetrated highly sheared metamorphosed rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Goldstein and Reno (1952, p. 2284).

County.—Falls.

Well name.—Humble Oil & Refining Company No. 1 Pucek.

Location.—L. Thurner survey; 2,917 feet FSWL, 217 feet FSEL; 4 mi. W and 6.5 mi. S of County Line.

Elevation.—426 feet. *Total depth.*—3,576 feet. *Completed.*—1929.

Top of metamorphic rocks.—3,535 feet. *Elevation of metamorphic rocks.*— -3,109 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: two sections unmarked as to depth.

Description of metamorphic rocks.—Sellards (1931b) reported that the core from 3,535 feet is similar to the Missouri Mountain slate; in a later publication (Sellards, 1933) he described the rock as phyllite.

Samples examined for this study are gray, reddish to purplish sericite slate veined with quartz. The reddish color is due to disseminated tiny grains of hematite; locally rutile needles are abundant. Metamorphism is weak; the original bedding intersects foliation and slaty cleavage at a high angle.

The well penetrated the interior zone of the Ouachita belt.

X-ray data.—I $>>$ K (Tr); 10/7 $\sim$ 20; F = 24?; SR = 10+; hematite, rutile(?).

References.—Sellards (1931b, p. 822; 1933, p. 188).

County.—Fannin.

Well name.—Callery, Incorporated, No. 1 R. G. Robinson.

Location.—S. M. Rainer survey; 1,980 feet FEL, 660 feet FNL.

Elevation.—714 feet. *Total depth.*—5,598 feet. *Completed.*—1952.

Top of Paleozoic rocks.—3,214 feet. *Elevation of Paleozoic rocks.*— -2,500 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3240–50, 3500–10, 3650–60, 4300–05, 4700–05 (2), 5590–95.

Description of Paleozoic rocks.—The rocks in this well are fine-grained, angular, poorly sorted, feldspathic quartz sandstone and dark silty metashale; the intergranular material in the sandstone is a mat of clay-sericite-chlorite which is slightly reconstituted. The heavy mineral fraction contains abundant angular garnet. The sequence is identified as Stanley.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—I > Ch > ML (Tr) > K(?); 10/7 $\sim$ 0.7; F = 20; SR = 2.5.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—Fannin.

Well name.—Cox Drilling Corporation No. 1 S. F. Leslie.

Location.—Maria Ignacio Giminez survey; 660 feet FSL, 467 feet FEL; ½ mi. W of Ector.

Elevation.—648 feet, kelly bushing; 638 feet, ground. *Total depth.*—4,116 feet. *Completed.*—1957.

Top of Paleozoic rocks.—2,560 feet. *Elevation of Paleozoic rocks.*— -1,912 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2620–30, 3100–10 (2), 3500–10, 3900–10, 4100–10 (2).

Description of Paleozoic rocks.—The sequence penetrated in this well is composed of: (1) fine-grained, mostly subangular to subround, fairly well-sorted, quartz sandstone, locally slightly dolomitic, feldspathic, or argillaceous; (2) angular to subangular well-sorted tightly packed micaceous and chloritic quartz siltstone; and (3) dark shale, locally pyritic, siliceous, or spiculitic. Radiolarian-bearing siliceous shale occurs at 4,100 feet. The rocks are cut by quartz veinlets; locally there appears to be incipient metamorphism. Although these rocks occur in a terrane where the neighboring wells have encountered Stanley beds, they do not resemble Stanley. Goldstein (1959) reported that the sample from 2,620 feet may be Atoka and that the deeper samples are Jackfork sandstone.

This well penetrated the frontal zone of the Ouachita structural belt.

X-ray data.—I > ML > Ch; 10/7 $\sim$ 1.3; SR = 1.5. The absence of feldspar is characteristic of Jackfork.

References.—Personal communication: R. A. Hall, Pan American Petroleum Corporation, 1957; August Goldstein, Jr., Bell Oil and Gas Company, 1959.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Fannin.

Well name.—Damon Oil Company No. 1 Chaffin.

Location.—J. Kuetchem survey; 4 mi. NE of Bonham.

Elevation.—568 feet. *Total depth.*—3,204 feet. *Completed.*—1942.

Top of Paleozoic rocks.—3,115 feet. *Elevation of Paleozoic rocks.*— -2,547 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 3100, 3130, 3150, 3200.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Paleozoic (Stanley?) at 3,115 feet with total depth 3,204 feet in Stanley(?).

The sequence is composed of fine- to very coarse-grained, angular, poorly sorted arkose. The rocks are unmetamorphosed, and although several samples show a resemblance to Stanley lithology, there appears to be more feldspar, particularly potassium feldspar, than is typical. Possibly the feldspar was derived from an uplifted foreland element such as the Muenster or Arbuckle blocks.

The well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—Fannin.

Well name.—Elkay Oil and Gas Company No. 1 Wilson Lane.

Location.—J. Bourland survey; 2,200 feet FWL, 1,700 feet FNL; 2 mi. NW of Ector.

Elevation.—700± feet. *Total depth.*—3,134 feet. *Completed.*—1921.

Top of Paleozoic rocks.—2,338(?) feet. *Elevation of Paleozoic rocks.*— -1,638±(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2375–80 (2), 2387–2410, 2430, 2440, 2450, 2454–56, 2460, 2500, 2515, 2530 (2), 2535, 2545, 2560, 2570, 2575, 2590, 2597–2605, 2610, 2625–30, 2630–40, 2640–58, 2658–70, 2675–94, 2694–2792, 2795, 2834, 2865, 2876–95.

Description of Paleozoic rocks.—Sample descriptions in the Bureau of Economic Geology files report gray to black shale locally slickensided, and indurated brown to gray sandstone from 2,338 to 3,134 feet; spicules were noted at 2,895, 3,007, and 3,127 feet. Miser and Sellards (1931) identified the sequence penetrated in this well as Stanley shale; Sellards (1933) described it as black shale and sandstone.

The section is unmetamorphosed to incipiently metamorphosed shale, siltstone, and fine-grained sandstone. The shales are dark colored, commonly contain fine quartz silt, carbonaceous debris, and mica shreds, and locally contain finely dispersed carbonate. The sandstones are fine-grained, tightly packed, mostly angular, poorly sorted argillaceous micaceous quartz sandstone containing chert grains and shale fragments. Goldstein (1959) reported the following petrographic determinations: 2,530 to 2,575 feet, Atoka; 2,590 to 2,630 feet, Atoka(?); 2,630 to 2,895 feet, Jackfork.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Miser and Sellards (1931, pp. 812–813); Sellards (1933, p. 188).
Personal communication: August Goldstein, Jr., Bell Oil and Gas Company, 1959.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Fannin.

Well name.—Hamilton-Powell Drilling Company No. 1 Losche.

Location.—Robert Kerr survey; 4,010 feet FNL, 990 feet FEL; 18 mi. N of Bonham.

Elevation.—565 feet. *Total depth.*—6,408 feet. *Completed.*—1952.

Top of Paleozoic rocks.—2,200 feet. *Elevation of Paleozoic rocks.*— -1,635 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2500–10, 2700–10, 2800–10, 3020–30, 3250–60 (2), 3530–40, 3920–30 (2), 4820–30 (3), 5550–60 (3), 6350–60 (3).

Description of Paleozoic rocks.—Coon (1955) reported top of Paleozoic 2,190 to 2,210 feet; the Paleozoic sequence consists of alternating dark shale and fine-grained greenish-gray sandstone and siltstone, locally quartzitic.

Thin section study shows the sequence is primarily dark carbonaceous and micaceous shale and fine-grained angular to subround, poorly to fairly well-sorted quartz sandstone, locally feldspathic. One section (2700–10) contains metashale, but in general the rocks are unmetamorphosed. The sandstones show better rounding and sorting, contain less clay, less feldspar, and more carbonate than typical Stanley sandstone and do not contain garnet in the heavy mineral fraction. The rocks are identified as Jackfork sandstone.

The well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: L. A. Coon, The Texas Company, 1955; H. J. Morgan, Jr., The Atlantic Refining Company, 1955; August Goldstein, Jr., Bell Oil and Gas Company, 1959.

County.—Fannin.

Well name.—E. V. Parsons (George L. Pace?) No. 1 R. E. Morgan.

Location.—J. C. English survey; 3 mi. E, 1 mi. N of Savoy.

Elevation.—666 feet. *Total depth.*—3,048 feet. *Completed.*—1930.

Top of Paleozoic rocks.—2,280 feet. *Elevation of Paleozoic rocks.*— −1,614± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3515–18, 3521–22, 3546–48, 3598–99 (2), 3641–44 (2), 3656–60, 3664–65, 5534–36.

Description of Paleozoic rocks.—In notes in the Bureau of Economic Geology files, Sellards described samples from 2,794, 2,999, 3,042, 3,045, and 3,048 feet as gray quartzitic siltstone. Miser and Sellards (1931) identified samples from this well as Stanley shale; later Sellards (1933) described the sequence as hard shale and sandstone.

Thin section study shows a sequence composed of fine-grained, angular, poorly to fairly well-sorted quartz sandstone, commonly argillaceous, micaceous, calcareous, and/or slightly feldspathic, dark silty shale, and calcareous micaceous siltstone. Quartz veins are present. The sandstones differ from Stanley sandstones in that they contain less clay and feldspar, are generally better sorted, and do not have the characteristic garnet in the heavy mineral fraction (cf. Hamilton-Powell No. 1 Losche). There is no metamorphism. The rocks are identified as Jackfork sandstone.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—I > Ch (ML Tr?); 10/7 ∼ 4; SR = 1.6. The absence of feldspar is characteristic of Jackfork sandstone.

References.—Miser and Sellards (1931, pp. 813–814); Sellards (1933, p. 188). Samples are in Bureau of Economic Geology Well Sample Library.

County.—Fannin.

Well name.—Sun Oil Company No. 1 Tucker.

Location.—Juan M. Zepada survey; 3 mi. N of Leonard.

Elevation.—660 feet. *Total depth.*—3,854 feet. *Completed.*—1955.

Top of Paleozoic rocks.—3,755 feet. *Elevation of Paleozoic rocks.*— −3,095 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3760–70, 3790–00, 3820–30.

Description of Paleozoic rocks.—Means (1956) reported base of Cotton Valley and top of Paleozoic brown chert, 3,755 feet; top of black chert and black siliceous shale, 3,790 to 3,800 feet.

Thin section shows dark cryptocrystalline chert rich in dark organic material, commonly containing cavities lined with chalcedony and filled with black bituminous material; quartz veins are common and bitumen occurs in the centers of the veins. The rocks are Bigfork chert.

The well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. A. Means, Sun Oil Company, 1956.

County.—Fannin.

Well name.—Texas Minerals No. 1 Snowden (Wharton?).

Location.—William Rice survey; 1,060 feet FEL, 2,580 feet FSWL; 2 mi. E and slightly S of Whitewright.

Elevation.—707 feet. *Total depth.*—4,100 feet. *Completed.*—1944.

Top of Paleozoic rocks.—3,210 feet. *Elevation of Paleozoic rocks.*— −2,503 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3395–3425 (2), 3456–86 (2), 3537–42 (2), 3542–47 (2), 3557–62 (2).

Description of Paleozoic rocks.—The sequence is composed of dark silty shale and fine-grained, angular to subangular, poorly sorted, feldspathic quartz sandstone, locally argillaceous and micaceous; there is a high percentage of garnet in the heavy mineral suite. The rocks are identified as Stanley shale.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—I > Ch > ML > K(?); 10/7 ~ 1; F = 20; SR = 2.5.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1955; H. A. Sellin, Magnolia Petroleum Company, 1956.

County.—Fannin.

Well name.—U. S. Epperson Underwriting Company No. 1-A W. L. Helton.

Location.—Daniel Young survey; 467 feet S along EL of Dalton survey, thence 617 feet E to location.

Elevation.—602± feet. *Total depth.*—5,916 feet. *Completed.*—1952.

Top of Paleozoic rocks.—3,440(?) feet. *Elevation of Paleozoic rocks.*— -2,838±(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—This well was drilled as "a tight hole." A scout inferred the presence of steeply dipping beds because the driller was unable to maintain a straight hole with normal drilling weight. Based on location, this well penetrated the frontal zone of the Ouachita belt in an area where the subcrop might be either Stanley or pre-Stanley Ouachita facies rocks.

X-day data.—None.

References.—Personal communication: E. M. Hurlbut, Jr., Shell Oil Company, 1956; H. J. Morgan, Jr., The Atlantic Refining Company, 1957.

County.—Freestone.

Well name.—Humble Oil & Refining Company No. 1 Marberry.

Location.—S. P. Flint survey; 660 feet FSL, 660 feet FWL.

Elevation.—459 feet. *Total depth.*—13,595 feet. *Completed.*—1952.

Top of Paleozoic rocks.—13,452 feet. *Elevation of Paleozoic rocks.*— -12,993 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 13,270, 13,279, 13,373, 13,387, 13,452, 13,453, 13,457-62, 13,462-67, 13,472-76, 13,481-86, 13,486-91, 13,496-01, 13,501-06, 15,530-35, 13,540-45, 13,545-50, 13,550-55, 13,560-61, 13,561-64, 13,567-73, 13,577-90.

Description of Paleozoic rocks.—According to Woods (1956), this well penetrated a normal section of upper Jurassic rocks and encountered olivine basalt from 13,266 to 13,452 feet; from 13,452 feet to total depth the sequence is composed of brecciated red hematitic quartzitic sandstone with streaks of red sandy shale. Thin section shows cataclastic and hydrothermal metamorphism of slate grade (determination by P. H. Masson).

Hurlbut (1958) noted the presence of 10 feet of red shale beneath the basalt; he believed that this red shale (possibly Eagle Mills) is separated from the quartzite sequence below by a fault. Another possibility is that the red shale is a weathered zone at the top of the metamorphosed sequence.

The predominant rock type in the sequence beneath the basalt is a hard, red, fine-grained, angular to round, fairly well-sorted to poorly sorted, hematitic argillaceous feldspathic quartzitic quartz sandstone containing abundant chert grains, locally dolomitic, calcareous, chloritic, or sericitic, and commonly veined with hematite, quartz, chlorite, and/or dolomite; there are minor amounts of angular hematitic micaceous feldspathic quartzitic siltstone with shaly or slaty layers in the sandstone sequences. Mica in the siltstone-shale is second-cycle mica and new sericite and is commonly well oriented; some of these rocks are micaceous clay-slates. In the upper part of the sequence the sandstones contain detrital feldspar (both microcline and sodic plagioclase) and relatively large rock fragments of quartzite (silica-cemented standstone) and chert; lower in the sequence there is abundant alkali feldspar interstitial to secondarily enlarged quartz grains—this feldspar appears to be authigenic and comprises as much as 50 percent of the rock. In some parts of the rock quartz grains are completely welded together by silica cement. In one section hematite and chlorite occur as pseudomorphs after magnetite(?).

The provenance of these sandstones seems to have been older sedimentary rocks as indicated by the grains of quartzite and the diverse characters of the quartz grains which include straight extinguishing quartz (locally with inclusions of biotite), weakly undulose quartz, and strongly undulose quartz and composite grains. It is very difficult to assess the degree of metamorphism because of the obscuring effects of hematite and clay (white reflecting, montmorillonite?) which seem to have leached down from the overlying section of altered basalt, and because of the relatively simple quartz-feldspar mineralogy. Reconstituted mica-chlorite in some of the slaty rocks suggests a very weak or weak metamorphism; the abundant authigenic feldspar indicates a strong hydrothermal element.

This well is east of highly sheared low-grade metamorphic rocks of the interior zone; the relationship of these rocks to the more highly metamorphosed sequence is unknown and their age is unknown. General lithology indicates a Paleozoic age. Goldstein (1959) believed that these rocks are low-grade metamorphic rocks—equivalent in grade to other rocks of the interior zone—but possibly metamorphosed by nearby igneous intrusion. Another possibility is that they are post-orogenic late Paleozoic rocks altered by nearby igneous activity; the lithology is compatible with a post-orogenic facies.

X-ray data.—None.

References.—Personal communication: E. M. Hurlbut, Shell Oil Company, 1958; R. D. Woods, Humble Oil & Refining Company, 1956; August Goldstein, Jr., Bell Oil and Gas Company, 1959. Samples are in Bureau of Economic Geology Well Sample Library.

County.—Frio.

Well name.—Magnolia Petroleum Company No. 1 McKinley.

Location.—Davidson survey; 1,320 feet FNL, 660 feet FWL; 6½ mi. NE of Pearsall.

Elevation.—614 feet. *Total depth.*—11,951 feet. *Completed.*—1947.

Top of metamorphic rocks.—11,910 feet. *Elevation of metamorphic rocks.*— −11,296 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 11,945–51.

Description of metamorphic rocks.—Morgan (1952) stated that this well passed out of the Comanche at 10,380 feet and encountered mica schist at 11,910 feet. The interval between is occupied by red shale with thin-bedded reddish to white limestone, red sandstone and conglomerate; Morgan reported that fusulinids of Wolfcamp age were found in seven limestone beds between 11,630 and 11,900 feet, and he identified this sequence as Permo-Pennsylvanian in age.

If Morgan is correct in this age assignment, the most likely explanation is that these sandstones and shales are late Paleozoic post-orogenic beds preserved in a structural low within the metamorphic terrane (cf. Pagenkopf No. 1 Blum in Bexar County). An alternative explanation is that they are Mesozoic beds (Jurassic) containing reworked older fusulinids.

The metamorphic rocks in this well are garnetiferous biotite-chlorite-muscovite-quartz schists; spongy garnet porphyroblasts are commonly associated with chlorite, suggesting retrogressive metamorphism. Locally, the foliation is convoluted. Metamorphism is low to medium grade—the schist in this well shows as high a metamorphic grade as has been encountered in the Ouachita structural belt. The well penetrated the interior zone of the Ouachita belt and provides one of the southernmost control points.

X-ray data.—None.

References.—Goldstein and Reno (1952, p. 2289); H. J. Morgan (1952, p. 2272).

County.—Gonzales.

Well name.—Quintana Petroleum Corporation No. 1 Lampkin.

Location.—Winslow Turner League; 660 feet FSEL, 1,980 feet SW of highway; 1½ mi. NW of Slayden.

Elevation.—340 feet. *Total depth.*—9,177 feet. *Completed.*—1944.

Top of metamorphic rocks.—8,580 feet. *Elevation of metamorphic rocks.*— −8,240 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 8580–85, 8600–05, 8617–21, 8738–53 (2), 8770–76 (2), 8815–30, 8935–50 (2), 9058–75 (2), 9150–56 (2).

Description of metamorphic rocks.—The sequence is composed of dark-colored, fine- to coarse-grained, angular to subround, very poorly sorted, sericitic chloritic high-rank metasandstone and dark-colored pyritic carbonaceous sericite slate, both extensively veined with quartz. Quartz sand grains are undulose, fractured, and commonly consist of fragments of broken quartz veins. Rocks are foliated and fracture cleavage is developed. Metamorphism is weak with a high shearing element.

The rocks resemble the dark, sheared slate sequence found in northern Guadalupe and Caldwell counties rather than the phyllite-metaquartzite sequence immediately to the north in Caldwell County (Pl. 2). Metamorphism appears to be less intense than in areas to the north closer to the Luling front. This well suggests that perhaps the black slate belt is repeated in the subcrop south of the phyllite-metaquartzite belt.

X-ray data.—None.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1956.

County.—Grayson.

Well name.—Burton et al. (Burton Syndicate, Zee-Tex Oil Company) No. 1 Cannon.

Location.—Alex. Martin survey; SW of corner; 1 mi. N of Tioga.

Elevation.—ni. *Total depth.*—1,956(?) feet. *Completed.*—1922.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Information in the Bureau of Economic Geology files indicates that this well bottomed in a gray-banded sandstone of Pennsylvanian age.
From the location, it appears that the well penetrated Strawn or Atoka beds west of the Ouachita front.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Grayson.

Well name.—Continental Oil Company No. 1 B. F. Armstrong.

Location.—Ignatius Carrico survey; 660 feet FSL, 1,700 feet FWL; 3 mi. NE of Sherman.

Elevation.—710 feet, derrick floor. *Total depth.*—10,150 feet. *Completed.*—1957.

Top of Paleozoic rocks.—1,919 feet. *Elevation of Paleozoic rocks.*— -1,209 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2100–10 (2), 2170–80, 2260–70, 2470–80, 2490–2500, 2520–30, 2570–80, 2590–2600, 2700–10, 2810–20, 2950–70, 3000–10, 3140–50, 3360–70, 3460–70, 3550–60, 3620–30, 3650–60.

Description of Paleozoic rocks.—Creager (1957) reported the following determinations: base of Cretaceous and top of novaculite, 1,920 feet; top of Missouri Mountain, 2,245 feet; top of Polk Creek, 2,460 to 2,480 feet; top of Viola (Bigfork), 2,480 feet; top of Des Moines (Pennsylvanian), 3,490 feet.
The following subdivision of the sequence is based on thin section examination: (1) samples 2,100 to 2,110 and 2,170 to 2,180 feet are dark black argillaceous spiculitic cryptocrystalline chalcedonic chert containing dark organic material, locally dolomitic, and light-colored spiculitic cryptocrystalline chalcedonic chert containing local masses of dark organic matter and scattered dolomite rhombs—*Arkansas novaculite;* (2) samples 2,260 to 2,270 feet are dark red and green shale—probably *Missouri Mountain;* (3) samples 2,470–2,480, 2,490–2,500, 2,520–2,530, 2,570–2,580, 2,590–2,600, 2,700–2,710, 2,810–2,820, and 2,950–2,970 feet are dark dolomitic spiculitic argillaceous chert containing dark organic material, dark dolomitic spiculitic siliceous shale rich in organic matter, fine-grained dolomite, locally containing dark organic material, and fine-grained spiculitic dolomitic limestone, locally shaly—*Bigfork chert;* (4) samples 3,000 to 3,010 feet are dark gray-green shale or metashale—*Womble;* (5) samples 3,140 to 3,150 feet are fine-grained, round, well-sorted, slightly dolomitic quartzitic quartz sandstone—*Strawn*(?); (6) samples 3,360–3,370, 3,460–3,470, 3,550–3,560, 3,620–3,630, and 3,650–3,660 feet are unmetamorphosed fine-grained, subangular to round, fairly well-sorted, slightly argillaceous quartz sandstone, crushed and fractured—*Atoka.* The Ouachita facies rocks are veined with quartz, carbonate, and bituminous matter.
This well penetrated unmetamorphosed pre-Stanley Ouachita facies rocks, intersected a thrust fault, and bottomed in Pennsylvanian (Strawn-Atoka) sandstone and shale. There appears to be some discrepancy between the top of the Des Moines picked from sample examination and the petrographic determination of Strawn(?) (but definitely Pennsylvanian) at 3,140 to 3,150 feet. The well is in the frontal zone of the Ouachita belt close to the western margin.

X-ray data.—None.

References.—Personal communication: N. G. Creager, Continental Oil Company, 1957; R. F. Mathews, Continental Oil Company, 1957.

County.—Grayson.

Well name.—Verne Dumas Company et al. No. 1 M. E. (Mollie) Williams.

Location.—Ben Nix survey; 360 feet FWL, 350 feet FSL; 3.9 mi. NE of Van Alstyne.

Elevation.—790 feet. *Total depth.*—5,046(?) feet. *Completed.*—1933.

Top of Paleozoic rocks.—3,100(?) feet; 3,425(?) feet. *Elevation of Paleozoic rocks.*— -2,310(?) feet; -2,635(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3469, 3572–87, 4585–00, 4720–35.

Description of Paleozoic rocks.—Descriptions of sporadic samples (Bur. Econ. Geol. files) show red shale at 3,160 to 3,499 and 3,572 to 3,633 feet and note that fragments of brown chert occur in deeper samples—3,633–4,509, 4,535–4,562, 4,555–4,615, 4,585–4,660, 4,660–4,921, 5,046 feet; sandstone fragments are described in the last sample, 5,046 feet. Samples examined for this study are composed of dark cryptocrystalline to microgranular chert, locally containing dark organic material and dark silty metashale; the lithology is typically Bigfork.
This well penetrated lower Paleozoic Ouachita facies rocks in the frontal zone of the Ouachita

structural belt. An alternate interpretation is that the Ouachita facies rocks occur as fragments in Strawn conglomerates and the well is west of the Ouachita front.

X-ray data.—None.

References.—Sellards (1933, p. 189).
Personal communication: August Goldstein, Jr., Bell Oil and Gas Company, 1959; W. T. Smith, Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—Gace Milling Company No. 1 Exstein.

Location.—McMullen & McGloin survey; 1 mi. S of Red River, 10 mi. FW County line, 13 mi. W of Denison.

Elevation.—ni. *Total depth.*—ni. *Completed.*—ni.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Decription of Paleozoic rocks.—Information in the Bureau of Economic Geology files indicates that the sample at 2,742 feet is probably Strawn. This well is in foreland rocks west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Grayson.

Well name.—A. G. Hill No. 1 Ione Carter.

Location.—Ignatius Carrico survey; 330 feet FSL, 1,575 feet FWL.

Elevation.—704 feet, derrick floor; 694 feet, ground. *Total depth.*—6,938 feet. *Completed.*—1955.

Top of Paleozoic rocks.—1,920 feet. *Elevation of Paleozoic rocks.*— -1,216 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—The following data were reported by Wilson (1956): base of Cretaceous and top of Stanley(?), 1,920 feet; top of Arkansas novaculite, 2,280 feet; top of Missouri Mountain shale, 2,370 feet; top of Polk Creek shale, 2,440 feet; top of Bigfork chert, 2,700 feet; top of Womble shale, 3,185 feet; top of Bigfork chert and thrust fault, 3,300 feet; top of Womble shale, 3,500 feet; top of Pennsylvanian and thrust fault, 3,700 feet.

According to the sample determinations above, this well penetrated a normal Ouachita facies section with the lower part repeated by faulting, intersected a thrust fault, and bottomed in foreland Pennsylvanian rocks (lithology not described). The well penetrated an allochthonous plate in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: W. J. Wilson, Shell Oil Company, 1956.

County.—Grayson.

Well name.—Howell and Howell No. 1 J. C. Mulder.

Location.—J. Barefoot survey; Mulder field.

Elevation.—692 feet. *Total depth.*—7,888 feet. *Completed.*—1951.

Top of Paleozoic rocks.—1,670 feet. *Elevation of Paleozoic rocks.*— -978 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Kiene and McMahor (1952) reported production from Ellenburger rocks. This well penetrated foreland rocks west of the Ouachita belt.

X-ray data.—None.

References.—Kiene and McMahon (1952).

County.—Grayson.

Well name.—Olson Drilling Company No. 1 Southwestern Life Insurance Company (Mauldin).

Location.—Section 665, J. C. Jamison survey (J. C. Butler? survey); 1,160 feet FNL, 1,627 feet FEL, 6½ mi. W, 4 mi. N of Denison.

Elevation.—770 feet. *Total depth.*—5,890 feet. *Completed.*—1936.

Top of Paleozoic rocks.—1,010 feet. *Elevation of Paleozoic rocks.*— -240 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1460–70 (2), 1510–20, 2050–60 (2), 2600–10, 3280–90, 4030–40, 4455–61, 4461–63, 4720–30, 4820–30, 4870–76, 4950–60, 5090–00, 5300–10, 5450–60, 5800–10.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Trinity and top of Stanley, 1,010 feet; top of Arkansas novaculite, 4,485 feet; top of Missouri Mountain(?), 4,790 feet; top of Polk Creek(?), 4,860 feet; top of Bigfork, 4,890 feet; top of Womble, 5,270 feet; total depth 5,890 feet, in Womble.

Thin section examination shows typical Stanley lithology—dark shale and metashale interlayered with fine-grained, mostly angular, poorly sorted, argillaceous feldspathic quartz sandstone in the upper part of the sequence. The lower beds are dark dolomitic argillaceous chert containing organic material, dark dolomitic argillaceous limestone, dark fine-grained argillaceous dolomite, commonly siliceous, and dark metashale; Bigfork and Womble lithologies are clearly recognizable. The shales show incipient metamorphism throughout the sequence.

Graptolites in core fragments were studied by Berry (1959) who reported as follows: 4,879 to 4,891 feet, *Climacograptus*(?) cf. *C. eximius* Ruedemann; 5,453 to 5,454 feet, *Retiograptus geinitzianus* (Hall), *Dicellograptus sextans* (Hall), *Glyptograptus* sp., *Cryptograptus tricornis* (Carruthers), *Glossograptus hincksii* (Hopkinson), *Leptograptus flaccidus* var. *spinifer* mut. *trentonensis* Ruedemann; 5,457 feet, *Dicellograptus sextans* (Hall), *Glyptograptus* cf. *G. teretiusculus* (Hisinger), fragments of *Retiograptus geinitzianus* (Hall), and *Cryptograptus tricornis* (Carruthers). Berry noted that these graptolite forms are characteristic of the lower part of the Womble and Woods Hollow shales and are mid-Middle Ordovician in age.

The well penetrated upper and lower Ouachita facies rocks in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; W. T. Smith, Pan American Petroleum Corporation, 1955; W. J. Wilson, Shell Oil Company, 1956; W. B. N. Berry, University of California, 1959.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—Olson Drilling Company No. 1 Utiger.

Location.—P. P. Cudy (Cady?) survey; center of survey.

Elevation.—722 feet. *Total depth.*—6,000 feet. *Completed.*—1937.

Top of Paleozoic rocks.—950 feet. *Elevation of Paleozoic rocks.*— -228 feet.

Thin section coverage.—SHELL OIL COMPANY: 1700–10. BUREAU OF ECONOMIC GEOLOGY: 960–70, 1060–70, 1360–70, 1450–60 (2), 1920–30, 2050–60, 2500–10, 4100–10, 5150–60.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Arkansas novaculite, 950 feet; top of Missouri Mountain(?), 1,270 feet; top of Bigfork, 1,320 feet; top of Womble, 2,030 feet; total depth 6,000 feet, in Womble.

Thin section examination shows a typical pre-Stanley Ouachita facies sequence composed of dark-colored dolomitic cherts containing organic material, locally spiculitic, and dark siliceous metashales. The 1,450 to 1,460 interval is fine-grained fossiliferous siliceous dolomitic limestone and dark green metashale containing "pleochroic" carbonate porphyroblasts (siderite?).

The well penetrated pre-Stanley Ouachita facies rocks showing incipient metamorphism in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; W. T. Smith, Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—Pan American Production Company No. 1 J. Umphress.

Location.—Eli Jones (Jonas?) survey; 2,000 feet FNL, 1,950 feet FWL; 5½ mi. SW of Whitewright.

Elevation.—664 feet. *Total depth.*—8,896 feet. *Completed.*—1952.

Top of Paleozoic rocks.—3,304 feet. *Elevation of Paleozoic rocks.*— -2,640 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 4520–30, 4540–50, 4610–20, 4690–00, 4820–30, 6190–00, 6220–30, 6230–40, 6330–40, 6350–60, 6390–00, 6440–50, 6500–10, 6530–40, 7010–20, 7080–90 (3), 7130–40, 7150–60, 7450–60, 7560–70, 7600–10, 7760–70, 7975–80, 7980–00, 8180–90, 8330–40, 8520–30, 8710–20, 8800–10, 8830–50.

Description of Paleozoic rocks.—Goldstein (1955) reported top of Bigfork, 3,346 feet; top of Womble (graptolite-bearing), 3,750 feet; top of Pennsylvanian of foreland facies (boulder-bearing mudstone or conglomerate), 6,175 feet. Morgan (1955) stated that Pennsylvanian (Deese beds—Strawn) is reported beneath Ouachita facies rocks at 6,180 feet.

The sequence below 6,175 feet is composed of a mixture of various types of chert, fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone with more or less carbonate, carbonate rocks containing abundant sand and silt, and fairly well-sorted and rounded argillaceous to calcareous quartz sandstone. The heterogeneous suite of rocks associated with Pennsylvanian type sandstone suggests a conglomerate or some type of sedimentary rock carrying exotic fragments (see Goldstein's interpretation above).

If the interpretation of a thrust fault at 6,175 feet is correct, this well penetrated pre-Stanley rocks of Ouachita facies and bottomed in Pennsylvanian rocks, probably of Atoka or Strawn age.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955, 1959; H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—Grayson.

Well name.—Peter and Johnson (McCarty Oil Company) No. 1 J. A. O'Dell.

Location.—T. R. Shannon survey; 2 mi. SE of Denison.

Elevation.—ni. *Total depth.*—ni. *Completed.*—1927.

Top of Paleozoic rocks.—1,560± feet. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1945(2).

Description of Paleozoic rocks.—Sample descriptions in the Bureau of Economic Geology files show red and gray shale from 1,780 to 1,945 feet. Miser (Miser and Sellards, 1931) examined samples from 1,580 to 1,945 feet and identified the sequence as Missouri Mountain shale and Polk Creek shale. Getzendaner (1943) commented on the pre-Trinity red sandstones, shales, and conglomerates in this and other wells in the area.

Cuttings from 1,945 feet are dark silty shale containing varied amounts of mica, bitumen, and fine "pin-point" carbonate; the rocks cannot be identified from this single sample.

If Miser's identification is correct, this well penetrated older Ouachita facies rocks in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Getzendaner (1943, p. 1229); Miser and Sellards (1931, p. 815).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—Peter Oil and Gas Company, Incorporated, No. 1 Butcher (also known as Peter No. 1).

Location.—Polly Ann Boon survey; SE corner; 3 mi. E of Denison.

Elevation.—725 feet. *Total depth.*—4,025 feet. *Completed.*—1922.

Top of Paleozoic rocks.—1,511 feet. *Elevation of Paleozoic rocks.*— −786 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 3340 (2). BUREAU OF ECONOMIC GEOLOGY: 1678 (4), 1702, 1945, 1970 (2), 2070, 2435, 2460 (2), 2530–75 (2), 2960–75, 3340 (5), 3345, 3800, 3888–3919, 3945–4003, 3975, 4023.

Description of Paleozoic rocks.—Sample descriptions in the Bureau of Economic Geology files report a sequence of black shale, locally slickensided, and gray sandstone; cone-in-cone limestone occurs in the sample at 3,340 feet; black siliceous shales occur in the lower part of the sequence. White calcite veins are present, but Udden noted that the samples are not so extensively veined as in wells in Bell and Williamson counties. An excerpt (undated) from a letter from the United States Geological Survey to H. A. Jones notes that the sequence was identified by K. C. Heald as probably Stanley. Miser (Miser and Sellards, 1931) identified the rocks as Stanley; Sellards (1933) described the sequence as black shale and sandstone.

The rocks are dark shale and fine-grained, mostly angular, poorly sorted, argillaceous feldspathic quartz sandstone, commonly containing a substantial amount of garnet in the heavy mineral fraction; thin limestone beds in the sequence have cone-in-cone structure.

This well penetrated Stanley beds in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Miser and Sellards (1931, p. 815); Sellards (1933, p. 189).
Samples in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—Peter Oil and Gas Company, Incorporated, No. 1 Jackson.

Location.—William Wright survey; SE corner; 2 mi. S of Denison.

Elevation.—700± feet. *Total depth.*—1,708(?) feet. *Completed.*—1920.

Top of Paleozoic rocks.—828± feet. *Elevation of Paleozoic rocks.*— −128± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in the Bureau of Economic Geology files report a sequence of red, purple, green-gray, and brown shales from 1,400 to 1,700 feet. Getzendaner (1943) reported 500 feet of red shale, sandstone, and conglomerate of pre-Trinity age. The age and facies of these rocks are unknown.

X-ray data.—None.

References.—Getzendaner (1943, p. 1229).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—Peter Oil and Gas Company, Incorporated, No. 1 Munson (No. 2 Munson; also known as Preston No. 1 Munson and Preston No. 2 Munson).

Location.—Ramon Rubio survey; 2½ mi. N of Denison.

Elevation.—605 feet (from topographic map). *Total depth.*—3,640 feet. *Completed.*—1922.

Top of Paleozoic rocks.—2,370± feet. *Elevation of Paleozoic rocks.*— −1,765± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2700–30, 3147, 3250.

Description of Paleozoic rocks.—Notes in the Bureau of Economic Geology files report black shale and gray sandstone from scattered samples between 2,525 and 3,260 feet; reference is made to observations by K. C. Heald, who reported dark gray to black siliceous shale, tentatively identified as Stanley. Miser and Sellards (1931), discussing the No. 1 Munson, stated that K. C. Heald examined samples from 3,140 to 3,260 feet and identified them as Stanley. Miser and Sellards (1931, p. 816) discussed a No. 2 Munson well 2½ miles north of Denison, and Miser said that the cuttings from 2,370 to 3,260 feet are Stanley; the sequence is described by Sellards (1933) as black shale and sandstone. This seems to be the same as the No. 1 Munson.

Three samples available for study are dark, angular, bituminous micaceous chloritic calcareous argillaceous quartz siltstone, dark bituminous shale, and fine-grained, angular to subround, poorly sorted, micaceous chloritic calcareous quartz sandstone; scattered siliceous spicules occur in the siltstone. These three samples are non-diagnostic. The sandstone and siltstone contain too much calcite and too little feldspar to be typical Stanley lithology.

This well penetrated Stanley(?) in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Miser and Sellards (1931, pp. 815–816); Sellards (1933, p. 189).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—W. J. Rutledge No. 1 M. E. (Mollie) Williams.

Location.—Solomon Nix survey; 3½ mi. NE of Van Alstyne.

Elevation.—790 feet, derrick floor. *Total depth.*—5,309 feet. *Completed.*—1938.

Top of Paleozoic rocks.—3,460 feet. *Elevation of Paleozoic rocks.*— −2,670 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3530–40, 3800–10, 4910–20.

Description of Paleozoic rocks.—Sample descriptions by E. R. Applin in the files of the Bureau of Economic Geology show chert pebble conglomerate (Strawn conglomerate) and red and green shale from 3,460 to 4,500 feet and mostly green, red-brown, and gray shale from 4,500 to 5,309 feet.

The first two thin sections above (3530–40, 3800–10) are dark argillaceous microgranular to cryptocrystalline chert containing dark organic material (Bigfork formation); the 4910–20-foot interval contains calcareous sandy and silty brown shale and calcareous argillaceous quartz sandstone. The sandstone is Pennsylvanian (Strawn) type.

Two interpretations of this well merit consideration: (1) The well passed out of the Cretaceous and directly into Pennsylvanian conglomerates containing chert pebbles from the Bigfork chert, or (2) the well passed from Cretaceous rocks into Bigfork chert (and Womble shale?), intersected a thrust fault, and penetrated Pennsylvanian beds. The existence of an overthrust fault in this area is demonstrated by other wells to the north and east and perhaps to the south (p. 172; Pl. 2). If Applin's interpretation from sample studies is correct and the well passed directly into Strawn beds, there would appear to be a re-entrant in the overthrust (due to pre-Cretaceous erosion) or a fenster in this area.

X-ray data.—None.

References.—Bureau of Economic Geology files.
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—Seitz, Comegys and Seitz No. 1 W. P. Mackay (Mackoy) (McKay) (MacKey).

Location.—J. Bridges survey; 3 miles SE of Whitesboro Mackoy field, Macomb area.

Elevation.—760 feet. *Total depth.*—3,834 feet. *Completed.*—1952.

Top of Paleozoic rocks.—1,790 feet. *Elevation of Paleozoic rocks.*— -1,030 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Smith (1953) reported total depth in Strawn with production from Strawn sand. This well is located west of the Ouachita belt and penetrated foreland rocks. A second well in this area, No. 2 W. P. Mackay, achieved production from Ellenburger rocks.

X-ray data.—None.

References.—Smith (1953, p. 1387); Bradfield (1957, p. 24).

County.—Grayson.

Well name.—Shell Oil Company No. 1 R. O. Brown.

Location.—J. W. Vandever survey; 330 feet FNL, 330 feet FWL; 2 mi. S of Pottsboro; South Pottsboro field.

Elevation.—710 feet, derrick floor. *Total depth.*—8,500 feet. *Completed.*—1954.

Top of Paleozoic rocks.—1,993 feet. *Elevation of Paleozoic rocks.*— -1,283 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2303¼, 3590–3600 (2), 3790–3800, 4590–4600, 5790–5800, 6590–6600, 7140–50, 7390–7400, 7690–91½.

Description of Paleozoic rocks.—Wilson (1959) reported top of Paleozoic (Des Moines) at 1,993 feet; top of Atoka at 8,135 feet.

The sequence is composed of (1) dark silty and sandy shale and siltstone; (2) fine- to medium-grained, angular to subround, fairly well sorted to poorly sorted, argillaceous quartz sandstone commonly containing abundant fragments of shale and chert, locally containing calcite cement; and (3) dark fine-grained fossiliferous limestone (7,140 to 7,150-foot interval). Fragments of chert in the 3,590 to 3,600-foot interval are probably derived from pebbles.

The rocks are Strawn and Atoka; the well penetrated foreland rocks immediately west of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: W. J. Wilson, Shell Oil Company, 1959.

County.—Grayson.

Well name.—Sherman City Well.

Location.—Sherman, Texas.

Elevation.—720 feet. *Total depth.*—2,366 feet. *Completed.*—1922.

Top of Paleozoic rocks.—2,350± feet. *Elevation of Paleozoic rocks.*— -1,630± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Getzendaner (1943) listed this well as having penetrated about 500 feet of pre-Trinity beds composed of red shale, sandstone, and conglomerate—age unknown.

X-ray data.—None.

References.—Getzendaner (1943).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—Simpson-Fells Oil Company No. 1 G. W. Wall.

Location.—George B. Reeves survey; 42 feet FWL, 965 feet FNL; 8 mi. WNW of Denison.

Elevation.—734 feet. *Total depth.*—2,515 feet. *Completed.*—1927.

Top of Paleozoic rocks.—900± feet. *Elevation of Paleozoic rocks.*— -166± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 972, 987–89, 1065, 1137–38, 1178, 1187 (2), 1198 (2), 1202–04, 1220–24, 1240, 1269–73, 1274–80, 1291–94, 1300–02, 1300–03, 1305–13, 1327–32, 1367–70, 1390–93, 1432–42, 1506–15, 1532–40, 1583–93, 1618–45, 2084–86, 2217–39.

Description of Paleozoic rocks.—Miser (Miser and Sellards, 1931) described the section from 900 to 1,552 feet as flint, calcareous chert, and siliceous limestone of the Bigfork chert, and the lower unit, 1,552 to 2,515 feet, as Stringtown shale containing graptolites of the same fauna as found in the Womble. Sellards (1933) placed the top of the Paleozoic at 963± feet. Goldstein (1955) reported base of Trinity and top of Bigfork, 900 feet; possible top of Womble, 1,374 feet; definitely in Womble, 1,739 feet; in Womble at 2,515 feet—last sample.

Thin section study shows a sequence of dark, fine-grained, commonly spiculiferous argillaceous dolomitic limestone and dark chert containing organic matter, commonly spiculitic, and commonly containing carbonate rhombs, overlying dark pyritic locally dolomitic slightly silty shale. Fine-grained light gray limestone is present in the 2,084 to 2,086 and 2,217 to 2,239-foot intervals.

This well penetrated lower Paleozoic Ouachita facies rocks including Bigfork chert and Womble shale in the frontal zone of the structural belt.

X-ray data.—None.

References.—Miser and Sellards (1931, pp. 817–818); Sellards (1933, p. 189).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—H. W. Snowden et al. No. 1 A. M. Bryant.

Location.—E. M. Jones survey; 1,768 feet S, 1,060 feet W of NW cor. A. Hilburn survey.

Elevation.—782 feet, derrick floor. *Total depth.*—4,471 feet. *Completed.*—1946.

Top of Paleozoic rocks.—3,285 feet. *Elevation of Paleozoic rocks.*— -2,503 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—According to Davis (1959), this well penetrated Ouachita facies rocks: top of Arkansas novaculite, 3,285 feet; top of Missouri Mountain shale, 3,770 feet; top of Bigfork chert, 4,140 feet; total depth 4,471 feet, in Bigfork chert.

This well penetrated lower Paleozoic Ouachita facies rocks in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: H. W. Davis, The Texas Company, 1959.

County.—Grayson.

Well name.—Snuggs and Cox No. 2 M. M. Davis et al.

Location.—W. G. Miller survey; Collinsville field.

Elevation.—691 feet. *Total depth.*—3,990 feet. *Completed.*—1955.

Top of Paleozoic rocks.—1,810 feet. *Elevation of Paleozoic rocks.*— -1,119 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—This well achieved production from foreland facies rocks west of the Ouachita belt.

X-ray data.—None.

References.—C. E. Davis (1956, p. 1197).

County.—Grayson.

Well name.—Snuggs and Neal No. 1 Q. Little.

Location.—W. M. Allen survey; Big Mineral field.

Elevation.—669 feet. *Total depth.*—3,629 feet. *Completed.*—1951.

Top of Paleozoic rocks.—1,750 feet. *Elevation of Paleozoic rocks.*— -1,081 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—This well achieved production from Strawn beds; other wells in the field penetrated lower Paleozoic foreland facies rocks.

This well is located west of the Ouachita front.

X-ray data.—None.

References.—None.

County.—Grayson.

Well name.—Standard Oil Company of Texas No. 1 Mitchell.

Location.—J. McNair survey; 2 mi. NW of Sherman.

Elevation.—751 feet. *Total depth.*—11,541 feet. *Completed.*—1946.

Top of Paleozoic rocks.—2,370 feet. *Elevation of Paleozoic rocks.*— -1,619 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 4140–50, 4240–50, 4640–50, 6370–80, 6560–70, 6700–10, 6710–20, 6960–70, 7740–50, 8260–70, 8580–90, 8590–00 (2), 8600–10, 8700–10, 9420–30, 10,140–50, 11,000–10.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Strawn, 2,370 feet; top of Atoka, 6,735 feet; top of Viola, 9,130 feet; top of Simpson (Bromide), 9,300 feet; top of McLish, 9,770 feet; top of Oil Creek, 10,100 feet; top of Joins, 11,000 feet; top of Ellenburger, 11,240 feet; total depth 11,540 feet, in Ellenburger. Morgan (1952) made the following analysis: base of Comanche, 2,370 feet; 2,370 to 6,757 feet, red and gray shales, sandstones, and in some places conglomerates, with a few thin limestone beds at the base—the rocks show no metamorphism and cores show a low dip—a fusulinid of Strawn age was found at 6,740 to 6,750 feet; from 6,785 to 9,117 feet the beds are hard black abundantly slickensided and polished shales and hard quartzitic sandstones which in two cores showed nearly vertical dips; 9,117 to 9,298 feet, limestone similar to the Viola; 9,298 feet to total depth, beds resembling Simpson. According to Morgan's interpretation, late Paleozoic beds overlie Ouachita facies rocks and the unconformity can be dated as pre-Strawn, post-Bend; Morgan made no explanation of the foreland facies Ordovician rocks beneath the strata he calls Ouachita facies except to compare the situation encountered in Magnolia No. 1 Wardlaw in Kinney County.

Thin section examination shows that the clastic section is composed mostly of fine-grained, poorly to fairly well-sorted, calcareous and/or feldspathic argillaceous quartz sandstone; beds of fine-grained fossiliferous limestone occur in the sandstone sequence. These rocks more closely resemble Pennsylvanian rocks of foreland facies than Ouachita facies; it appears that Strawn and Atoka beds rest on foreland facies Ordovician rocks and the well penetrated a foreland facies section west of the Ouachita belt. Apparently, the Atoka sequence was deformed prior to Strawn deposition (see p. 126).

X-ray data.—None.

References.—H. J. Morgan (1952, pp. 2271–2272).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Grayson.

Well name.—Standard Oil Company of Texas No. 1 O'Hanlon.

Location.—A. T. Cooke survey; 615 feet FSL, 660 feet FEL; 3 mi. NW of Sherman.

Elevation.—878 feet, derrick floor. *Total depth.*—10,312 feet. *Completed.*—1955.

Top of Paleozoic rocks.—2,090 feet. *Elevation of Paleozoic rocks.*— -1,212 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Bradfield (1957) presented the following section: red Strawn (Deese), gray Strawn (Deese), Dornick Hills, Viola(?). Wilson (1959) reported top of Paleozoic (Des Moines) at 2,090 feet and top of Atoka at 8,540 feet. This well encountered foreland facies rocks very close to the Ouachita front.

X-ray data.—None.

References.—Bradfield (1957, p. 41).
Personal communication: W. J. Wilson, Shell Oil Company, 1959.

County.—Grayson.

Well name.—Starr Oil Company, Incorporated, No. 1 Blankenship.

Location.—Seymour Bradley survey; 6 mi. SE of Pottsboro.

Elevation.—696 feet. *Total depth.*—6,542 feet. *Completed.*—1953.

Top of Paleozoic rocks.—2,005 feet. *Elevation of Paleozoic rocks.*— -1,309 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3400–10, 3600–10 (2), 3700–10, 4400–10, 5295–00.

Description of Paleozoic rocks.—According to Morgan (1955) this well encountered Ordovician strata of Ouachita facies below the Comanche, penetrated a thrust fault, and bottomed in Pennsylvanian (Deese beds—Strawn). Tims (1957) reported base of Cretaceous and top of Ouachita facies (Womble), 2,010 feet; thrust fault and top of Pennsylvanian (Bruhlmeyer sand of Deese formation), 5,230 feet; total depth 6,542 feet, in Bruhlmeyer sand.

Thin section examination shows a sequence of dark shale and metashale, locally brecciated, fine-grained argillaceous glauconitic fossiliferous limestone, light-colored cryptocrystalline to microgranular chert, and dark red shale containing organic material, overlying fine-grained, subangular to subround, fairly well-sorted quartz sandstone. The upper part of the Paleozoic sequence is composed of Ordovician Ouachita facies rocks, probably Bigfork-Womble, although X-ray data do not confirm this identification (see below); the lower sandstone is of foreland facies—Strawn.

This well penetrated lower Paleozoic Ouachita facies rocks in the frontal zone of the Ouachita belt, transected a thrust fault, and bottomed in foreland rocks.

X-ray data.—ML > I > K > Ch; SR = 1.0. Womble(?). The upper sample is composed predominantly of mixed-layer illite-montmorillonite, which is not characteristic of Ouachita facies rocks.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1955; V. E. Tims, Standard Oil Company of Texas, 1957.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Grayson.

Well name.—Starr Oil Company, Incorporated, No. 1 W. A. Moser.

Location.—J. C. Parks survey; 1,100 feet FSL, 660 feet FEL; 3 mi. SE of Pottsboro.

Elevation.—732 feet, derrick floor. *Total depth.*—5,427 feet. *Completed.*—1952.

Top of Paleozoic rocks.—2,030 feet. Elevation of Paleozoic rocks.— −1,298 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Wilson (1959) reported top of Paleozoic rocks (Des Moines) at 2,030 feet. No samples were available for study. From its location, this well is close to the Ouachita front, probably just to the west in Des Moines beds. Without samples no positive determination can be made.

X-ray data.—None.

References.—Personal communication: W. J. Wilson, Shell Oil Company, 1959.

County.—Grayson.

Well name.—Tennessee Gas Transmission Company No. 1 Washburn.

Location.—Aaron Burleson survey; 72 feet FSL, 1,506 feet FEL.

Elevation.—681 feet, derrick floor. *Total depth.*—13,421 feet. *Completed.*—1955.

Top of Paleozoic rocks.—2,750 feet. *Elevation of Paleozoic rocks.*— −2,069 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—The following stratigraphic information is reported (Davis, 1959): base of Cretaceous and top of Strawn, 2,750 feet; top of Atoka, 9,033 feet; top of Simpson, 12,555 feet; top of Arbuckle, 13,273 feet; total depth 13,421 feet, in Arbuckle.

This well penetrated foreland facies rocks close to the Ouachita front; the Atoka sequence, abnormally thick for this area, overlies truncated Ordovician rocks.

X-ray data.—None.

References.—Personal communication: H. W. Davis, The Texas Company, 1959.

County.—Grayson.

Well name.—The Texas Company No. 1 John Marshall.

Location.—A. Tuttle survey; 2½ miles S of Sandusky; Sandusky field.

Elevation.—703 feet. *Total depth.*—7,885 feet. *Completed.*—1950.

Top of Paleozoic rocks.—1,523 feet. *Elevation of Paleozoic rocks.*— −820 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—The following stratigraphic information is reported: top of Simpson, 6,668 feet; top of Oil Creek, 7,270 feet; top of Ellenburger, 7,543 feet; the well was completed as an Ellenburger producer. This well penetrated foreland rocks west of the Ouachita structural belt.

X-ray data.—None.

References.—Anonymous (1951, p. 269).

County.—Grayson.

Well name.—Westover et al. (Westover Oil Company) No. 1 Easton (Peter Oil and Gas Company, Incorporated, No. 2 Easton).

Location.—Polly Stamps survey; 1,050 feet FWL, 2,150 feet FNL; 9 mi. NW of Denison.

Elevation.—690 feet. *Total depth.*—1,070 feet. *Completed.*—1920.

Top of Paleozoic rocks.—830± feet. *Elevation of Paleozoic rocks.*— -140± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sellards (Bur. Econ. Geol. files) described a core from 1,015 feet as black shale and hard sandstone with bedding dipping at 55° to 60°; he compared the rock with cores from Griffiths et al. No. 1 Evans (Sunset ranch) in Travis County and remarked that the core from the No. 1 Easton is not so indurated or extensively veined as the rock from Travis County. Miser and Sellards (1931) reported Stanley shale dipping at 60°; Sellards (1933) described the rock as hard sandstone.

This well penetrated Stanley shale in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Miser and Sellards (1931, p. 818); Sellards (1933, p. 189).
Personal communication: W. T. Smith, Pan American Petroleum Corporation, 1955.

County.—Guadalupe.

Well name.—Diamond Half Oil Company No. 1 Bibbs.

Location.—J. B. Robinson survey; 660 feet FNEL, 660 feet FSEL.

Elevation.—509 feet. *Total depth.*—5,508 feet. *Completed.*—1937.

Top of metamorphic rocks.—5,440 feet. *Elevation of metamorphic rocks.*— -4,931 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 5440–50, 5450–60(?).

Description of metamorphic rocks.—The rocks penetrated in this well are partly mylonitized metaquartzite, locally sericitic, and talc-dolomite marble. Metamorphism is low grade with a high shearing and crushing element. The well penetrated the interior zone of the Ouachita belt.

X-ray data.—I, F = 22(?); SR = 17.2.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Guadalupe.

Well name.—Frank Gravis No. 1 Weyel.

Location.—E. de los Santos Coy survey; 3½ mi. NW of Marion.

Elevation.—798 feet, derrick floor. *Total depth.*—2,588 feet. *Completed.*—1946.

Top of metamorphic rocks.—2,500 feet. *Elevation of metamorphic rocks.*— -1,702 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2574–76.

Description of metamorphic rocks.—The single sample examined for this study is a green chlorite-sericite slate containing quartz grains and fragments of sheared vein quartz; micaceous minerals are bent around the quartz grains. Metamorphism is weak with a high shearing element.

This well penetrated the black slate belt in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Guadalupe.

Well name.—Cecil Hagen No. 1 Henry Calvert et al.

Location.—John Ussery survey; 5,400 feet FWL, 3,150 feet FSL; 4½ mi. W of Kingsbury.

Elevation.—559 feet, derrick floor; 552 feet, ground. *Total depth.*—4,391 feet. *Completed.*—1947.

Top of metamorphic rocks.—4,260(?) feet; 4,238(?) feet. *Elevation of metamorphic rocks.*— -3,701(?) feet; -3,679(?) feet.

Thin section coverage (depth in feet).—None.

Description of metamorphic rocks.—On the basis of location, this well probably penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957.

County.—Guadalupe.

Well name.—Magnolia Petroleum Company No. 1 Frances Baker.

Location.—H. Cottle survey; 10,175 feet FSWL, 330 feet FNWL; 6 mi. NW of Luling.

Elevation.—402 feet. *Total depth.*—4,705 feet. *Completed.*—1952.

Top of metamorphic rocks.—4,682 feet. *Elevation of metamorphic rocks.*— −4,280 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4693–97 (2).

Description of metamorphic rocks.—Samples examined are sericite phyllite, locally hematitic. Metamorphism is low grade with a strong shearing element; structures include foliation, slaty cleavage, and fracture cleavage.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—$I > Ch > K$; $10/7 \sim 3$; $F = 24(?)$; $SR = 14.4$.

References.—Personal communication: R. E. Wills, Jr., Magnolia Petroleum Company, 1953. Samples are in Bureau of Economic Geology Well Sample Library.

County.—Guadalupe.

Well name.—Magnolia Petroleum Company No. 1 Murphy Pfulman.

Location.—G. W. Williamson survey.

Elevation.—509 feet. *Total depth.*—5,146 feet. *Completed.*—1948.

Top of metamorphic rocks.—5,140 feet. *Elevation of metamorphic rocks.*— −4,631 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 5140–42, 5142–44, 5145–46.

Description of metamorphic rocks.—Samples examined are highly sheared metaquartzite; metamorphism is low grade with a strong shearing component; structures are foliation and grain-stretching.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: R. E. Wills, Jr., Magnolia Petroleum Company, 1953.

County.—Guadalupe.

Well name.—Adolph Seiderman (New Braunfels Oil Company) No. 1 Alvina Seiderman.

Location.—A. Maria Esmaurrizar survey; from SE cor. N along EL 26,600 feet, thence W 35,200 feet; 2½ mi. SE of New Braunfels.

Elevation.—628 feet, derrick floor; 625 feet, ground. *Total depth.*—2,955 feet. *Completed.*—1934.

Top of metamorphic rocks.—2,853 feet. *Elevation of metamorphic rocks.*— −2,225 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2636, 2695–2713, 2767–71, 2850–51, 2954–55.

Description of metamorphic rocks.—According to scout report, top of Trinity is 2,576 feet, top of Pennsylvanian is 2,650 to 2,660 feet, and top of schist is 2,885 to 2,895 feet. A second well, the No. 2 Alvina Seiderman, was drilled 150 feet from the No. 1 and reportedly topped black schist at 2,639 feet.

This well penetrated a sequence of highly sheared and deformed dark chlorite-sericite slates which vary from dark red hematitic slates to black pyritic and graphitic slates. Pre-shearing vein quartz occurs as brecciated masses and augen; post-shearing quartz veins are abundant. Metamorphism is weak with a very strong shearing component; structures are foliation, shear fractures, wrinkling, contortion, and brecciation.

The well penetrated the black slate belt in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Guadalupe.

Well name.—Stanolind Oil and Gas Company No. 1 Schmidt.

Location.—Gustavus Bunson survey; 1,320 feet FNWL, 660 feet FNEL; 4 mi. E of Selma.

Elevation.—815 feet. *Total depth.*—2,641 feet. *Completed.*—1954.

Top of metamorphic rocks.—2,582 feet. *Elevation of metamorphic rocks.*— −1,767 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: two sections marked core No. 38.

Description of metamorphic rocks.—Cores and thin sections are dark gray to black sericite slate containing masses of crushed and sheared vein quartz. Metamorphism is weak with a very high shearing element; slaty cleavage is well developed.

This well penetrated weakly metamorphosed highly sheared rocks of the black slate belt in the interior zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 ~ 1.5; SR = 3.9.

References.—Personal communication: J. B. Souther, Pan American Petroleum Corporation, 1956.
Cores are in Bureau of Economic Geology Well Sample Library.

County.—Hays.

Well name.—Bob Antibus et al. No. 1 J. Howe.

Location.—L. Wortel survey; 375 feet FSL, 1,800 feet FEL; 1½ mi. SW of Buda.

Elevation.—760 feet, derrick floor. *Total depth.*—2,380(?) feet; 2,830(?) feet. *Completed.*—1939.

Top of Paleozoic rocks.—2,240 feet. *Elevation of Paleozoic rocks.*— –1,480 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2240–62, 2338(2).

Description of Paleozoic rocks.—The few samples available for study are dark, fine- to medium-grained, angular, poorly sorted, carbonaceous(?) chloritic micaceous feldspathic low-rank metagraywacke and dark pyritic silty metashale or clay-slate veined by quartz. The abundant rock fragments in the graywacke are mostly chert, quartz mosaic, and slate-phyllite; new sericite and chlorite fibers penetrate grain boundaries. Metamorphism is very weak. These rocks appear to be part of the dark clastic unit of unknown age that forms the subcrop in the southeastern part of the frontal zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 ~ 1.2; F = 20(?); SR = 5.4.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Hays.

Well name.—E. A. Bucklin No. 1 A. A. Elsner.

Location.—S. J. Fowler survey; 3 mi. S of Dripping Springs.

Elevation.—1,075 feet (from topographic map). *Total depth.*—2,460 feet. *Completed.*—1929.

Top of Paleozoic rocks.—700± feet. *Elevation of Paleozoic rocks.*— +375± feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1400. BUREAU OF ECONOMIC GEOLOGY: 725–50, 795–815, 815–830, 1025, 1285, 1420 (2), 1585, 2330, 2425.

Description of Paleozoic rocks.—Sellards (1931b, p. 822) reported sandstone and black shale and (p. 827) quoted Miser's opinion that the interval 725 to 835 feet resembles Missouri Mountain slate with the bottom samples possibly Polk Creek shale. Goldstein (1955) stated that the well penetrated slightly altered greenish-gray shale beneath the Cretaceous and drilled maroon and gray-green shale from 720 to 835 feet; below this point samples consist of black altered shale, siltstone, and silty fine-grained quartz sandstone. Sample descriptions in the files of the Bureau of Economic Geology are as follows: 688 to 1,135 feet, brown, red, green, gray, and black shale; 1,135 to 2,300 feet, black shale cut by calcite veins; 2,300 to 2,425 feet, black shale with some chert.

Thin section examination shows a sequence of sericitic and chloritic clay-slate and micaceous dolomitic siltstone invaded by quartz and carbonate veinlets; most of the silica is in veinlets, but in one sample (siliceous clay-slate) silica was disseminated. The siltstone is generally poorly sorted and composed of angular quartz grains with minor plagioclase and more or less clay. Metamorphism ranges from incipient to very weak and the clay-slate shows incipient foliation.

This well penetrated Ouachita facies rocks (lower Paleozoic?) in the frontal zone of the Ouachita belt—possibly in an area of overthrusting (Pl. 2).

X-ray data.—I > Ch; 10/7 ~ 0.6; F = 20; SR = 4.5. The sequence shows well-crystallized chlorite-illite with no mixed layering.

References.—Sellards (1931b, pp. 822, 827).
Bureau of Economic Geology files.
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Hays.

Well name.—Harley and Whittington No. 1 Heidenreich.

Location.—Pace, Hemphill, and Carson survey; 720 feet FSEL; 253 feet FSWL; 3 mi. SE of Kyle.

Elevation.—632 feet. *Total depth.*—2,767 feet. *Completed.*—1931.

Top of metamorphic rocks.—2,750± feet. *Elevation of metamorphic rocks.*— -2,118± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2757, 2767.

Description of metamorphic rocks.—Sellards (1931b) described the rock as dark schistose shale. Sample descriptions in files of Bureau of Economic Geology are as follows: 2,750 feet, hard black metamorphosed shale with streaks of green material; 2,767 feet, dark green schistose shale and vein quartz.

Thin section study shows that the sequence is composed of dark siliceous sericite slate, sheared and brecciated, and invaded by massive quartz-carbonate-chlorite veinlets.

This well penetrated highly sheared rocks of the black slate belt in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1931b, p. 822; 1933, p. 189).

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Hays.

Well name.—Mann No. 1 Reeder.

Location.—R. Vaughn survey; 3,520 feet FNL, 2,750 feet FEL.

Elevation.—1,101 feet, derrick floor; 1,100 feet, ground. *Total depth.*—3,370 feet. *Completed.*—1939.

Top of Paleozoic rocks.—900± feet. *Elevation of Paleozoic rocks.*— +201± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 875–85, 890–900, 920–35(2), 985–1000, 1025–40(2), 1055–70.

Description of Paleozoic rocks.—Maner (1958) identified the sequence in this well as Stanley(?). The sequence is composed of (1) fine-grained (locally containing coarse grains and pebbles), angular, very poorly sorted, micaceous chloritic feldspathic quartz sandstone containing abundant rock fragments (metaquartzite, schist, phyllite, vein quartz mosaic, metasiltstone, chert, shale, microgranular volcanic rock); locally the sandstone contains fine interstitial carbonate; (2) angular, micaceous chloritic feldspathic sandy quartz siltstone, locally containing dark streaks of pyritic-bituminous material; and (3) dark silty carbonaceous metashale. One carbonate veinlet was observed. The second-cycle mica includes faded biotite; the only common heavy mineral is zircon. Metamorphism ranges from incipient to very weak.

These rocks are Mississippian-Pennsylvanian rocks of Ouachita facies; probably correlative with Stanley-Tesnus.

X-ray data.—I $>$ Ch; 10/7 $\sim$ 2; SR $=$ 2.7.

References.—Personal communication: R. P. Maner, Shell Oil Company, 1958.

County.—Hays.

Well name.—Shell Oil Company No. 1 Harwell.

Location.—M. H. Denham survey; 7½ mi. SW of Dripping Springs.

Elevation.—1,387 feet. *Total depth.*—4,661 feet. *Completed.*—1956.

Top of Paleozoic rocks.—820 feet. *Elevation of Paleozoic rocks.*— +567 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 860–70 (2), 866–76 (2), 1040–50, 1050–60, 1480–90 (3), 1840–50 (3), 2330–40 (2).

Description of Paleozoic rocks.—The following stratigraphic information is reported: top of Pennsylvanian, 820 feet; top of Mississippian, 2,420 feet; top of Ellenburger, 2,430 feet; total depth 4,661 feet, in Ellenburger.

The lower part of the sequence is composed of Marble Falls and Ellenburger rocks; the Marble Falls is a dark spiculiferous limestone containing a mixture of clay and organic material. The overlying Pennsylvanian beds are fine- to medium-grained, angular to subround, poorly to fairly well-sorted, argillaceous calcareous feldspathic quartz sandstone and dark, locally silty shale or metashale; the shales are deformed and brecciated. The sandstones contain abundant chert and phyllite fragments and as much as 10 to 15 percent plagioclase feldspar.

In all probability the Pennsylvanian sequence is Atoka; the abundant plagioclase is not typical of the Atoka west of the structural belt in the Fort Worth basin, but over-all sandstone lithology and stratigraphic position (overlying Marble Falls) suggest Atoka. The change from a normal Ellenburger—Marble Falls foreland sequence to a clastic sequence containing metamorphic rock fragments, feldspar, and showing incipient metamorphism reflects tectonism in this part of the structural belt immediately before and during Atoka deposition. The source of these sediments was probably a belt of overthrusting immediately to the south (see Pl. 2); post-Atoka orogeny and the proximity of the Llano buttress resulted in deformation and incipient metamorphism of the Atoka beds.

This well penetrated incipiently metamorphosed foreland rocks close to or within the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: P. T. Fowler, Shell Oil Company, 1956.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Hays.

Well name.—Woodward No. 1 Schubert.

Location.—Lot 26, Otis G. Eels survey; ½ mi. NW of Niederwald.

Elevation.—590 feet. *Total depth.*—3,338 feet. *Completed.*—1955.

Top of metamorphic rocks.—3,290 feet. *Elevation of metamorphic rocks.*— −2,700 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3297–3305, 3305–33, 3333–38.

Description of metamorphic rocks.—The sequence is composed of dark dolomitic quartzitic metasandstone, micaceous dolomitic metaquartzite, and black graphitic augen slate. Metamorphism is weak to low grade with strong shearing element; foliation is locally warped and folded.

The well penetrated highly sheared rocks of the black slate belt in the interior zone of the Ouachita belt.

X-ray data.—$I > Ch$; $10/7 \sim 1.1$; $F = 20$ and 24?.

References.—Cores are in Bureau of Economic Geology Well Sample Library.

County.—Hill.

Well name.—California-Texas Oil Company No. 1 Mastin (Maston).

Location.—James Ship survey; 3½ mi. SW of Grandview.

Elevation.—750 feet (from topographic map). *Total depth.*—3,870 feet. *Completed.*—ni.

Top of Paleozoic rocks.—1,600± feet. *Elevation of Paleozoic rocks.*— −850± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3370, 3765.

Description of Paleozoic rocks.—A driller's log in the files of the Bureau of Economic Geology reports a sequence of dark to black shale and gray sandstone. The two samples available for study are non-diagnostic dark silty shale. From the location of the well and the samples and sample descriptions available, this well probably penetrated Atoka beds west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Hill.

Well name.—Hillsboro City Well No. 1.

Location.—0.6 mi. W of Courthouse, at city water works, Hillsboro, Texas.

Elevation.—635 feet. *Total depth.*—2,136 feet. *Completed.*—1912.

Top of Paleozoic rocks.—1,900± feet. *Elevation of Paleozoic rocks.*— −1,265± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Barnes (*in* Sellards, 1933, p. 135) described the rocks from this well as quartzite and phyllite and said ". . . the less resistant rocks of this series show considerable recrystallization." No samples were available for study, but from the location of the well, the amount of metamorphism reported by Barnes is anomalous; the well is within the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1933, pp. 135, 189); Sundstrom et al. (1948, p. 159).

County.—Hill.

Well name.—Hillsboro City Well No. 2 (White and Green Drilling Company).

Location.—Near Well No. 1, 0.6 mi. W of Courthouse, at city water works, Hillsboro, Texas. (This may be the same as City Well No. 1.)

Elevation.—634 feet. *Total depth.*—2,152 feet. *Completed.*—1919.

Top of Paleozoic rocks.—1,810± feet. *Elevation of Paleozoic rocks.*— −1,176± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology report a sequence of gray to black shale (red shale at top) and hard sandstone. Sellards (1931b) described the sequence as shale and quartzitic sandstone. From the location of the well and the general lithology, it probably penetrated Stanley shale in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1931b, p. 822; 1933, p. 189); Sundstrom et al. (1948, p. 159).

County.—Hill.

Well name.—Hillsboro City Well No. 3 (Market Square Well).

Location.—0.1 mi. NE of Well No. 1; 0.6 mi. W of Courthouse, Hillsboro, Texas.

Elevation.—625 feet. *Total depth.*—1,838 feet. *Completed.*—1922(?); 1930(?).

Top of Paleozoic rocks.—1,794± feet. *Elevation of Paleozoic rocks.*— −1,169 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1838.

Description of Paleozoic rocks.—Sellards (1931b) reported shale and quartzitic sandstone. Thin section study shows the rocks are fine-grained, angular, poorly sorted, feldspathic, silty quartz sandstone with a substantial amount of garnet in the heavy mineral fraction—Stanley lithology.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1931b, p. 822); Sundstrom et al. (1948, p. 159).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Hill.

Well name.—Hill-Texas Oil Company (B. H. Harrison et al.) No. 1 C. Weatherby (Weatherbee).

Location.—W. O. Merriwether survey; 330 feet FSL, 330 feet FEL; 3½ mi. SE of Hillsboro.

Elevation.—777 feet. *Total depth.*—4,000+ feet. *Completed.*—1929.

Top of Paleozoic rocks.—2,305 feet. *Elevation of Paleozoic rocks.*— −1,528 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 2835–45, 3761–70.

Description of Paleozoic rocks.—Sellards (1931b) identified the sequence in this well as probably Stanley-Jackfork; later (1933) he described the rocks as black shale and quartzitic sandstone. Goldstein (1955) reported top of Paleozoic, 2,305 feet; total depth 4,000 feet, in Stanley(?).

The two samples examined for this study are altered sandy and silty volcanic tuff and fine-grained micaceous siltstone. The rocks are unmetamorphosed. The presence of tuff suggests that the rocks are Stanley, which contains tuff beds in the lower part. The well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1931b, p. 826; 1933, p. 189).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Hill.

Well name.—Humble Oil & Refining Company No. 1 M. Holderman.

Location.—C. Sullivant survey; 750 feet FNL, 1,667 feet F most E'ly EL.

Elevation.—659 feet, derrick floor. *Total depth.*—3,398 feet. *Completed.*—1935.

Top of metamorphic rocks.—3,337 feet. *Elevation of metamorphic rocks.*— −2,678 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3350–56.

Description of metamorphic rocks.—The single sample examined for this study is a calcareous chloritic sericite phyllite; metamorphism is low grade with a pronounced shearing element. The well penetrated the interior zone of the Ouachita belt.

X-ray data.—$Ch > I > K$; $10/7 \sim 0.2$; $SR = 20$.

References.—Personal communication: T. H. Shelby, Jr., Humble Oil & Refining Company, 1956, 1957.

County.—Hill.

Well name.—J. H. Humphrey No. 1 J. E. Osborne.

Location.—E. S. Cabler survey; 5,650 feet FSWL, 1,500 feet FSEL; 5½ mi. SE of Live Oak.

Elevation.—747 feet, derrick floor. *Total depth.*—8,287(?) feet. *Completed.*—1953.

Top of Paleozoic rocks.—1,490 feet. *Elevation of Paleozoic rocks.*— −743 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1350–60, 2850–60, 3390–00, 4140–50, 4440–50, 4830–40, 5000–10, 6250–60, 6830–40, 6850–60, 6870–80, 7350–60, 7550–60, 7895–05, 7925–35.

Description of Paleozoic rocks.—Turner (1957) reported top of Atoka, 1,490 feet; top of Marble Falls, 6,949 feet; top of Mississippian(?), 7,276 feet; top of Barnett, 7,495 feet; top of Ellenburger, 7,863 feet.

The upper part of the sequence is typical Atoka lithology—interbedded dark silty shale and fine-grained, angular to subround, fairly well-sorted, quartz sandstone, locally slightly argillaceous and/or feldspathic and/or calcareous. Marble Falls—Barnett is dark fine-grained siliceous spiculitic limestone, locally sandy, containing dark organic matter and traces of glauconite, and black calcareous siliceous spiculitic shale, rich in organic matter. The Ellenburger is composed of fine-grained dolomite and fossiliferous dolomitic calcilutite, locally pelletiferous.

This well encountered foreland facies rocks west of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: G. L. Turner, Pure Oil Company, 1957.

County.—Hill.

Well name.—Hunt Oil Company No. 1 E. W. Wright.

Location.—John Hays survey; 660 feet FSL, 660 feet FWL; 3 mi. SE of Grandview.

Elevation.—620 feet. *Total depth.*—6,693 feet. *Completed.*—1948.

Top of Paleozoic rocks.—1,780 feet. *Elevation of Paleozoic rocks.*— −1,160 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1890–00, 2050–60, 2890–00 (2), 3200–10 (2), 6100–10 (2), 6670–80 (2).

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Paleozoic (Pennsylvanian), 1,780 feet; total depth 6,693 feet, in Pennsylvanian of normal(?) facies. Thin section examination shows a sequence of fine-grained, angular to subround, poorly to fairly well-sorted, calcareous quartz sandstone and dark silty and sandy shale which is probably Atoka.

This well penetrated rocks of foreland facies west of the Ouachita belt.

X-ray data.—$I > Ch > ML > K(?)$; $10/7 \sim 1.3$; $F = 20$; $SR = 2.3$.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Hill.

Well name.—A. P. Merritt No. 1 Henry Nors.

Location.—F. A. Tabor survey; 3 mi. SE of Aquila.

Elevation.—535 feet. *Total depth.*—3,127 feet. *Completed.*—ni.

Top of Paleozoic rocks.—1,624 feet. *Elevation of Paleozoic rocks.*— −1,089 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 1940–50, 2130–40, 2260–70.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Paleozoic Ouachita facies, 1,624 feet; total depth 3,127 feet, in Pennsylvanian(?). Thin section examination shows a sequence of fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone and dark shale. The sandstone contains garnet in the heavy mineral fraction and is identified as Stanley.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Hill.

Well name.—Phillips Petroleum Company No. 1-A Posey.

Location.—E. S. Wyman survey; 2,400 feet FWL, 467 feet F most N'ly S line; 2 mi. S of Brandon.

Elevation.—599 feet. *Total depth.*—6,622 feet. *Completed.*—1956.

Top of Paleozoic rocks.—2,615 feet. *Elevation of Paleozoic rocks.*— -2,016 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2620–30, 2680–90 (2), 2720–30, 2730–40, 2770–80, 2817, 2880–90, 2993, 3407 (3), 3830–40 (2), 3910, 3947, 4200–10, 4609 (2), 5182, 5192, 5383–98, 5480–90 (2), 6112–20, 6410–20 (2), 6620–21 (2).

Description of Paleozoic rocks.—This well encountered the top of the Stanley shale at 2,615 feet and bottomed in Stanley at 6,622 feet. A core from the 3,900 to 3,910-foot interval shows a dip of 75° to 80°. The sequence is composed of fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone and dark metashale; the sandstone contains abundant garnet in the heavy mineral fraction. Locally quartz veins are numerous. Metamorphism ranges from none to incipient and occurs mostly in the shales; locally, very weak metamorphism is present adjacent to quartz veins.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—$I > Ch$; $10/7 \sim 1$; $F = 20$; $SR = 1.5$ (shallow), 3.1 (deep).

References.—Personal communication: F. H. Olson, Phillips Petroleum Company, 1956, 1957.

County.—Hill.

Well name.—Phillips Petroleum Company and Garrett No. 1 J. R. Rose.

Location.—Francis Baldez survey; 1,300 varas FNL, 125 varas FEL; 5 mi. SSW of Whitney.

Elevation.—460 feet. *Total depth.*—3,349 feet. *Completed.*—1925.

Top of Paleozoic rocks.—1,600 feet. *Elevation of Paleozoic rocks.*— -1,140 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1660, 1700, 1800, 1900–10, 1911, 2040, 2160, 2762, 2772.

Description of Paleozoic rocks.—Sample descriptions in the Bureau of Economic Geology files report dark slickensided shale, dark gray carbonaceous siltstone, and hard gray sandstone, locally quartzitic. A driller's log indicates base of Cretaceous may be as high as 1,364 feet. Goldstein (1955) reported top of Paleozoic (probably Pennsylvanian), 1,600 feet; total depth 3,349 feet, in Pennsylvanian(?). The sequence is composed of fine-grained, mostly angular, poorly sorted, argillaceous micaceous quartz sandstone and siltstone, and dark silty shale containing abundant carbonaceous debris; locally, the sandstones are calcareous or quartzitic. This sequence is tentatively identified as Atoka. The sandstones are more angular and less sorted than most Atoka sandstones, but possibly this is due to proximity to the Ouachita front. Apparently, Atoka sandstones change in facies in this area and become more angular, less sorted, and contain more feldspar, mica, and rock fragments.

This well is located close to the Ouachita front, possibly in the frontal zone of the Ouachita belt, possibly west of it.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Hill.

Well name.—Sherman Drilling Company (Clarence Houseman et al.) No. 1 J. F. Griffith.

Location.—Samuel Waddell survey; SE corner; 10 mi. W of Hillsboro near Bethel Church.

Elevation.—625 feet (from topographic map). *Total depth.*—2,835 feet. *Completed.*—1930.

Top of Paleozoic rocks.—1,575± feet. *Elevation of Paleozoic rocks.*— -950± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2250–57, 2800–20.

Description of Paleozoic rocks.—Sample descriptions in Bureau of Economic Geology files report black shale and hard sandstone with some red shale at the top of the sequence. Two samples available for study are fine- to very fine-grained, fairly well-sorted, calcareous argillaceous quartz sandstone, locally quartzitic, locally slightly feldspathic and micaceous, and containing minor amounts of chert, stretched quartz mosaic, shale, and slate-phyllite.

This well encountered Atoka beds west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Hunt.

Well name.—American Liberty Oil Company No. 1 McNatt.

Location.—E. Murphy survey; 4,750 feet FSL, 850 feet FEL.

Elevation.—573 feet. *Total depth.*—6,890 feet. *Completed.*—1942.

Top of Paleozoic rocks.—6,870 feet. *Elevation of Paleozoic rocks.*— -6,297 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—A sample log (source unknown) shows "red slate." The lithology is probably similar to the No. 1 Norman and No. 1 Rutherford wells immediately to the south.

X-ray data.—None.

References.—Personal communication: Ann Carter, Shell Oil Company, 1958.

County.—Hunt.

Well name.—Humble Oil & Refining Company No. 1 E. M. Anderson.

Location.—J. Porter survey.

Elevation.—599 feet. *Total depth.*—6,273 feet. *Completed.*—1944.

Top of Paleozoic rocks.—6,198 feet. *Elevation of Paleozoic rocks.*— -5,599 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 6267–73 (3).

Description of Paleozoic rocks.—The driller's log reports "red slate." This sequence is composed of hematitic micaceous clay-slate(?) and hematitic chloritic micaceous quartz siltstone; the rocks are veined by quartz, carbonate, hematite, and chlorite. Metamorphism is difficult to assess because of the obscuring effect of the finely disseminated hematite—it appears to be very weak.

This well seems to have penetrated very weakly metamorphosed rocks of Ouachita facies, possibly weathered Stanley beds, possibly lower Paleozoic Ouachita facies beds. On the basis of tuff associated with similar red beds to the south in the No. 1 Norman, the sequence is identified as Stanley(?).

The well is in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Ann Carter, Shell Oil Company, 1958; R. D. Woods, Humble Oil & Refining Company, 1958.

County.—Hunt.

Well name.—Humble Oil & Refining Company No. 1 Norman.

Location.—Hiram Thompson survey; 720 feet FNL, 4,665 feet FWL.

Elevation.—559 feet. *Total depth.*—7,157 feet. *Completed.*—1944.

Top of Paleozoic rocks.—7,142 feet. *Elevation of Paleozoic rocks.*— -6,583 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 7135–50 (2), 7150–55.

Description of Paleozoic rocks.—This sequence consists of fine-grained, argillaceous silty devitrified tuff veined with quartz overlying dark red hematitic metashale, locally brecciated, hematitic microgranular chert, and dark red hematitic chloritic micaceous feldspathic quartz siltstone veined with quartz. Metamorphism is incipient.

The tuffaceous rocks in this well suggest Stanley because tuff occurs in the lower part of the Stanley in the Ouachita Mountains and no tuffaceous rocks are known from the lower Paleozoic Ouachita facies sequence. The abundant hematite probably indicates deep weathering of the Paleozoic rocks.

The well is in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: R. D. Woods, Humble Oil & Refining Company, 1958.

County.—Hunt.

Well name.—Humble Oil & Refining Company No. 1 Rutherford.

Location.—Samuel Lindsey survey.

Elevation.—540 feet. *Total depth.*—7,483 feet. *Completed.*—1943.

Top of Paleozoic rocks.—7,460 feet. *Elevation of Paleozoic rocks.*— -6,920 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 7455–60, 7460–65.

Description of Paleozoic rocks.—This sequence is composed of fine-grained slightly hematitic sandy devitrified rhyolite(?) tuff overlying dark hematitic shale veined with quartz and dark micaceous chloritic quartz siltstone veined with quartz and quartz-bitumen. Metamorphism ranges from none to incipient.

The tuffaceous rocks in this well suggest Stanley because tuff is known to occur in the basal part of the Stanley in the Ouachita Mountains and it is not known in older rocks. The abundant hematite probably indicates deep weathering of the Paleozoic rocks.

The well is in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: R. D. Woods, Humble Oil & Refining Company, 1958.

County.—Hunt.

Well name.—Westmount Drilling Company No. 1 Clark.

Location.—W. H. Williams survey; 440 feet FEL, 1,225 feet FNL.

Elevation.—677 feet. *Total depth.*—5,314 feet. *Completed.*—1939.

Top of Paleozoic rocks.—4,800± feet. *Elevation of Paleozoic rocks.*— −4,123± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—According to Trowbridge (1958), Paleozoic rocks encountered in this well are dark shale.

On the basis of location, this well probably penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Ann Carter, Shell Oil Company, 1958; R. M. Trowbridge, Tyler, Texas, 1958.

County.—Johnson.

Well name.—Alvarado Oil Company No. 1 M. S. Richardson.

Location.—Seth Morris survey; 3½ mi. W of Alvarado.

Elevation.—850 feet. *Total depth.*—3,538 feet. *Completed.*—1926.

Top of Paleozoic rocks.—1,600± feet. *Elevation of Paleozoic rocks.*— −750± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3232.

Description of Paleozoic rocks.—The driller's log in the files of the Bureau of Economic Geology reports a sequence of dark shale and light (gray) sandstone. The single sample studied is composed of fine fragments of dark silty shale and fine-grained, angular to subround fairly well-sorted, calcareous and argillaceous quartz sandstone, locally quartzitic, micaceous. The sequence is probably Atoka.

The well is west of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Johnson.

Well name.—Christie et al. No. 1 N. Peikoff.

Location.—Wm. Hickman survey; 3,725 feet FNEL, 6,100 feet FNWL; 2 mi. NW of Venus.

Elevation.—677 feet, derrick floor. *Total depth.*—8,809 feet. *Completed.*—1955.

Top of Paleozoic rocks.—1,840(?) feet. *Elevation of Paleozoic rocks.*— −1,163(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Turner (1957) reported top of Atoka, 1,840(?) feet; top of Barnett, 7,800 feet; top of Simpson(?), 8,185 feet; top of Ellenburger, 8,283 feet.

This well penetrated foreland rocks west of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: G. L. Turner, Pure Oil Company, 1957.

County.—Kendall.

Well name.—J. S. Abercrombie and Harrison Oil Company No. 1 Lena Kunz and Joe Nickel.

Location.—J. W. Cormack survey; 2,100 feet FNL, 550 feet FEL; 7 mi. N and 1 mi. E of Boerne.

Elevation.—1,352 feet. *Total depth.*—2,252 feet. *Completed.*—1930.

Top of Paleozoic rocks.—785 feet. *Elevation of Paleozoic rocks.*— +567 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 2055–61, 2167–70. BUREAU OF ECONOMIC GEOLOGY: 2250.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology are as follows: 1,895 feet, metamorphosed indurated black shale; 2,185, 2,205 to 2,210 feet, indurated metamorphosed black shale, green chloritic schist, reddish quartzite; 2,200 feet, light green micaceous schist. Sellards (1931b) reported top of altered Paleozoic at 1,895± feet and described the rock as schistose shale; he noted that unaltered Paleozoic beds were first encountered at about 800 feet. Goldstein (1955) noted first sample in Pennsylvanian at 1,840 feet; total depth 2,252 feet in Missouri Mountain(?).

The three samples available for examination are angular argillaceous quartz siltstone, fine-grained, angular, poorly sorted, argillaceous chloritic and sericitic silty sandstone, and chloritic siliceous metashale; all samples contain massive quartz, quartz-chlorite, and quartz-carbonate veinlets. The rocks show incipient metamorphism, possibly due in part to the massive veining. Notwithstanding the X-ray data, the section appears to be Ouachita facies, probably including Stanley beds overlying older rocks.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—$I > K > ML > Ch$; $10/7 \sim 0.4$; $SR = 1.7$. Shale shows mixed layer structures resembling shales of the foreland but also has a high content of kaolinite, which is anomalous.

References.—Sellards (1931b, p. 823; 1933, p. 189).

Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Kendall.

Well name.—Boerne City Well.

Location.—1 mi. N of Boerne, Texas.

Elevation.—1,500± feet. *Total depth.*—1,118 feet. *Completed.*—Before 1930.

Top of Paleozoic rocks.—925± feet. *Elevation of Paleozoic rocks.*— +575± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology for the intervals 1,012, 1,075, and 1,118 feet report dark gray shale. Sellards (1931b) described the rocks as schistose shale.

From its location, this well probably penetrated Ouachita facies rocks in the frontal zone of the belt.

X-ray data.—None.

References.—Sellards (1931b, p. 822).

County.—Kendall.

Well name.—Dixon Oil Company, Incorporated, No. 1 Ottmer Behr.

Location.—J. W. Wilson survey; 1,400 feet FEL, 823 feet from Guadalupe River.

Elevation.—1,274 feet. *Total depth.*—2,783 feet. *Completed.*—1932.

Top of Paleozoic rocks.—In the interval 425–570 feet. *Elevation of Paleozoic rocks.*—In the interval +704 to +849 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in the files of the Bureau of Economic Geology report the following information: base of Cretaceous and top of Pennsylvanian in the interval 425 to 570 feet; from 570 to 1,640 feet the sequence is composed of "partly metamorphosed" black shale and minor gray sandstone; top of Ellenburger occurs at 1,640 feet.

The interval 570 to 1,640 feet is probably Atoka.

This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Kendall.

Well name.—Magnolia Petroleum Company No. 1 Ed Below.

Location.—Section 881, B. Ficklin Irrigation Company survey; 2,786 feet F most S'ly SWL, 1,085 FSEL (inside line); 6 mi. W of Welfare.

Elevation.—1,724 feet, derrick floor; 1,712 feet, ground. *Total depth.*—6,512 feet. *Completed.*—1953.

Top of Paleozoic rocks.—1,007 feet. *Elevation of Paleozoic rocks.*— +717 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1104–08, 1142–46, 1160–65, 1220–25 (2), 1245–50 (2), 1290–95, 1340–45, 1365–70, 2260–65, 2805–08, 3040–50, 3150–55, 3200–05, 3285–90, 3540–45, 3675–80, 3820–50, 3850–55, 3890–95, 3911, 3920, 3942–47. SHELL OIL COMPANY: 3820–25 (2), 3850–55, 3890–95.

Description of Paleozoic rocks.—Barnes (1958) studied cores from 3,905 to 6,512 feet, total depth and reported the following sequence: 3,905 feet, in Marble Falls; top of Barnett, 3,934.5 feet; top of Chappel, 3,962.5 feet; top of Doublehorn, 3,964.0 feet; top of chert bed—Ives(?), 3,976.5 feet; top of Ellenburger, 3,977.0 feet; top of Wilberns, 5,490.0 feet; top of Morgan Creek, 6,195.0 feet; top of Welge, 6,340.0 feet; top of Lion Mountain, 6,360.0 feet; top of Cap Mountain, 6,400.0 feet; total depth in Cap Mountain. This is a normal foreland facies sequence. Sparry calcite veinlets with extensive twinning and bent twin lamellae cut these rocks and suggest deformation.

Marble Falls rocks are overlain by a sequence of Ouachita facies rocks, showing incipient to very weak metamorphism accompanied by fracturing and brecciation, which are divided into an upper sequence of dark shale, siliceous shale, and chert, and a lower sequence of dark shale, sandstone, and tuff. The upper sequence (1,007 to 1,365 feet) is composed largely of (1) dark metashale (locally clay-slate), commonly siliceous, chloritic, micaceous, dolomitic, commonly containing pyritized spicules, and fragments of radiolarian capsules, locally tuffaceous(?); commonly the rock is fractured, sliced, or brecciated and invaded by quartz, carbonate, and bitumen veinlets; and (2) dark microgranular to cryptocrystalline chert, commonly dolomitic, spiculitic, argillaceous, commonly fractured, brecciated, and invaded by quartz, carbonate, and bitumen veinlets. These rocks are identified as pre-Mississippian rocks of Ouachita facies and include Arkansas novaculite, Missouri Mountain(?), and Womble(?) lithologic types; possibly Stanley beds occur at the top of the sequence directly beneath the Cretaceous and overlying Arkansas novaculite. The lower sequence (1,365 to 3,890 feet) is composed largely of (1) dark shale or metashale, locally silty, siliceous, and veined with quartz, carbonate, and bitumen; (2) fine-grained, angular to subround, poorly sorted, argillaceous micaceous chloritic feldspathic quartz sandstone, locally slightly calcareous or dolomitic, and containing a relatively high percentage of garnet in the heavy mineral fraction; the mica includes faded biotite; the rocks are veined with quartz, carbonate, and bitumen; and (3) fine-grained argillaceous chloritic siliceous tuff (1,365 to 1,370-foot and 2,805 to 2,808-foot intervals). This sequence is composed of Mississippian-Pennsylvanian rocks of Ouachita facies which closely resemble the Stanley.

In summary, the sequence penetrated in this well from top to bottom consists of: (1) lower Paleozoic (pre-Mississippian) rocks of Ouachita facies showing incipient to very weak metamorphism; (2) upper Paleozoic rocks of Ouachita facies showing incipient to very weak metamorphism (Stanley type); (3) unmetamorphosed upper Paleozoic rocks of foreland facies (Marble Falls–Barnett–Chappel); and (4) unmetamorphosed lower Paleozoic rocks of foreland facies (Ellenburger and older rocks).

Descriptions of the lower beds are based on cores (3,900 feet to total depth). Descriptions of the upper beds are based on core chips and cuttings. The division of the Ouachita sequence into two groups is not clear cut but rather suggested by relative amounts of rock types. Possibly the rocks were mixed by complex faulting and folding; possibly the sequence contains abundant conglomerate and the rocks were mixed by sedimentary processes.

This well is interpreted as having penetrated a zone of overthrusting where Mississippian-Pennsylvanian rocks of Ouachita facies were thrust over Marble Falls rocks and in turn overridden by lower Paleozoic Ouachita facies rocks. The well is probably a short distance south of the Ouachita front. An alternative interpretation is that the rocks overlying Marble Falls beds are of Atoka age and made up of fragments of Ouachita rocks; according to this interpretation, the well is located a short distance north of the Ouachita front.

X-ray data.—Samples above 3,900 feet: $I > ML > K > Ch$; $10/7 \sim 1.0$; $F = 20$; $SR = 1.6$; hematite.

References.—Barnes (1959, p. 456).
Personal communication: V. E. Barnes, Bureau of Economic Geology, 1958, 1959; J. R. Sandidge, Magnolia Petroleum Company, 1957.
Cores and samples are in Bureau of Economic Geology Well Sample Library.

County.—Kendall.

Well name.—A. S. Mowinkle No. 1 J. Kasten (Kaston).

Location.—George Werner survey; 150 feet FNL, 2,660 feet FEL; 7½ mi. W of Kendalia.

Elevation.—1,392 feet. *Total depth.*—1,543 feet. *Completed.*—1930.

Top of Paleozoic rocks.—470 feet. *Elevation of Paleozoic rocks.*— +922 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology are as follows: 513 to 568 feet, green pyritic shale; 568 to 670 feet, gray and greenish-gray sandstone, sandy shale, and shale; 670 to 1,003 feet, dark unctuous glossy shale, locally slickensided; 824 feet, quartzitic sandstone. The sequence from 470 to 1,003 feet is probably Atoka. The top of the "Bend" is placed at 1,003 feet; 1,003 to 1,062 feet, dolomitic fossiliferous limestone; 1,062 to 1,127 feet, black pyritic siliceous limy spiculiferous shale. This is probably a Marble Falls–Barnett section. The top of the Ellenburger is placed at 1,127 feet. Goldstein (1955) reported probable top of Paleozoic, 470 feet; definitely in Paleozoic (Pennsylvanian) at 545 feet; base of Smithwick and top of Marble Falls, 1,003 feet; top of Barnett(?), 1,092 feet; top of Ellenburger, 1,118 feet; total depth 1,545 feet, in Ellenburger.

This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Kendall.

Well name.—Clarence Newton No. 1 Check Ranch.

Location.—G. W. Lindsey survey; 165 feet FNEL, 467 feet FWL; 3 mi. SW of Kendalia.

Elevation.—1,320 feet. *Total depth.*—2,339 feet. *Completed.*—1950.

Top of Paleozoic rocks.—600 feet. *Elevation of Paleozoic rocks.*— +720 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 640–50, 770–810, 970–80, 1350–60, 1600–40, 1870–80, 2320–30 (2).

Description of Paleozoic rocks.—The sequence consists of dark red hematitic metashale overlying a sequence of dark metashale, locally silty, and fine-grained mostly angular, poorly sorted, argillaceous micaceous chloritic feldspathic quartz sandstone. The abundant hematite in the upper part of the section is probably due to weathering. Metamorphism is incipient.

This sequence is composed of Mississippian-Pennsylvanian beds of Ouachita facies (Stanley-Tesnus). The well penetrated the frontal zone of the Ouachita belt south of the Llano uplift.

X-ray data.—$I > K > Ch > ML$ (K relatively abundant); $10/7 \sim 0.9$; $SR = 1.9$; hematite.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Kendall.

Well name.—Permian Oil Company No. 1 Bowles.

Location.—F. de la Luna survey; 150 feet FNL, 150 feet FWL; 6 mi. N of Boerne.

Elevation.—1,410 feet. *Total depth.*—1,550(?) feet; 2,485(?) feet. *Completed.*—1930.

Top of Paleozoic rocks.—1,195± feet. *Elevation of Paleozoic rocks.*— +215± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1545–50.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology for the intervals 1,195 to 1,200, 1,420 to 1,425, and 1,545 to 1,550 feet report indurated shale and quartzitic sandstone. Sellards (1931b) described the rock as schistose shale. Thin section examination shows that the rocks are dark silty shale and angular micaceous argillaceous quartz siltstone. The rocks are unmetamorphosed. This sequence is probably composed of Mississippian-Pennsylvanian rocks of Ouachita facies.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—$I > Ch$; $10/7 \sim 1$; $F = 20$; $SR = 3.0$ (1 sample).

References.—Sellards (1931b, p. 822; 1933, p. 189).

County.—Kendall.

Well name.—Seaboard Oil and Gas Company No. 1 W. H. Askey.

Location.—Miguel del Toro survey; 8 mi. W, 4 mi. N of Kendalia.

Elevation.—ni. *Total depth.*—1,005 feet. *Completed.*—1930.

Top of Paleozoic rocks.—565 feet. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Descriptions in the files of the Bureau of Economic Geology report gray to black shale. From its location, this well is probably in Atoka beds north of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Kendall.

Well name.—P. B. Sterling et al. No. 1 McCracklin.

Location.—B. G. Owen survey; 1,350(?), 1,800(?) feet FNL, 250(?), 150(?) feet FEL; 3½ mi. NW of Kendalia.

Elevation.—1,398 feet. *Total depth.*—1,480 feet. *Completed.*—1930.

In Paleozoic at 500 feet. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology report hard gray carbonaceous sandstone from 550 to 735 feet and black shale from 735 to 756 feet. Top of Ellenburger dolomitic limestone is placed at 756 feet. The upper clastic section is probably Atoka-Marble Falls-Barnett. Sellards (1933) listed top of Ordovician at 752 feet.

This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1948); Sellards (1933, p. 215).

Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1956.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Kendall.

Well name.—P. B. Sterling No. 1 W. Werner.

Location.—John F. Torrey survey; 150 feet FNL, 2,432 feet FEL; 3 mi. E of Sisterdale.

Elevation.—1,403 feet. *Total depth.*—926 feet. *Completed.*—1930.

Top of Paleozoic rocks.—548 feet. *Elevation of Paleozoic rocks.*— +855 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology are as follows: 736, 745 feet, gray sandstone and hard gray shale (Atoka?); 780, 790, 798, 835 feet, brown dense spiculitic crinoidal limestone (Marble Falls–Barnett?); 886 to 916 feet, hard dolomitic limestone (Ellenburger). Sellards (1933) records top of Ordovician at 780 feet.

This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1948); Sellards (1933, p. 215).

Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1956.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Kendall.

Well name.—Fred Turner, Jr., et al. No. 1 R. Linder.

Location.—J. C. Brown survey; 290 feet FSWL, 1,610 feet FSEL; 6 mi. S of Comfort.

Elevation.—1,678 feet. *Total depth.*—1,490 feet. *Completed.*—1939.

Top of Paleozoic rocks.—940 feet. *Elevation of Paleozoic rocks.*— +738 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 900–07, 963–70, 988–94, 1135–40, 1165–70, 1198–1202, 1400–10, 1478–81 (2).

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Paleozoic, 940 feet; in Missouri Mountain(?), 1,100 feet; top of Bigfork, 1,450 feet; last sample in Bigfork at 1,481 feet.

Farmer (1958) described the following section below the base of the Cretaceous; 15 feet of gray, green, and brown chert; 100 feet of gray slickensided shale with minor interbedded siltstone; 65-foot sample skip; 225 feet of bright red and green slickensided micaceous shale; 50 feet of gray shale; 70 feet of green shale; 25 feet of dark brown to black hard shale; black spicular chert and brown dolomite. He suggested that this might represent an Arkansas novaculite–Missouri Mountain–Bigfork sequence.

Thin section examination shows a sequence of calcareous argillaceous siltstone and sideritic sericitic metashale or clay-slate, locally siliceous, underlain by dark slightly calcareous and argillaceous chert containing dark organic material; quartz-bitumen veins are common. The rocks show incipient to very weak metamorphism.

This well penetrated lower Paleozoic Ouachita facies rocks in the frontal zone of the Ouachita structural belt, possibly in an allochthonous plate. Magnolia No. 1 Below (p. 278), 6,000 feet to the northeast, has a normal pre-Mississippian foreland facies section.

X-ray data.—None.

References.—Personal communication: R. E. Farmer, Shell Oil Company, 1958; August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Kerr.

Well name.—Evans et al. No. 2 Love.

Location.—Section 1594, CCSD & RGNG survey; 660 feet FSL, 1,320 feet FWL; ½ mi. FS, 1 mi. FW County line.

Elevation.—2,380 feet. *Total depth.*—5,878 feet. *Completed.*—Before 1932.

Top of Paleozoic rocks.—1,490 feet. *Elevation of Paleozoic rocks.*— +890 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Paleozoic (Pennsylvanian), 1,490 feet; top of Marble Falls(?), 5,540 feet; top of Ordovician, 5,580 feet; total depth 5,872 feet, in Ellenburger. Sellards (1933) listed top of Ordovician at 5,605 feet.

This well penetrated rocks of foreland facies north of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1933, p. 215).

Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Kerr.

Well name.—Ohio Oil Company No. 1 J. H. Soul (Saul?).

Location.—Section 47, TWNG survey; 330 feet FEL, 1,650 feet FNL; 6 mi. SW of Center Point.

Elevation.—1,756 feet. *Total depth.*—5,070 feet. *Completed.*—1945.

Top of Paleozoic rocks.—950 feet. *Elevation of Paleozoic rocks.*— +806 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Pennsylvanian, 950 feet; top of Ellenburger, 3,580 feet; total depth 5,070 feet, in Ellenburger.

This well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Kerr.

Well name.—G. L. Rowsey No. 1 R. B. Nowlin.

Location.—Juan Corona survey; 1,924 feet FNL, 661 feet FWL; 2 mi. NW of Camp Verde.

Elevation.—1,695 feet, derrick floor; 1,685 feet, ground. *Total depth.*—6,363 feet. *Completed.*—1954.

Top of Paleozoic rocks.—970(?) feet. *Elevation of Paleozoic rocks.*— +725(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—A scout card reported the following data: top of sand, 970 feet; top of Ellenburger, 4,580 feet. If these data are correct, the well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—None.

County.—Kerr.

Well name.—G. L. Rowsey No. 2 R. B. Nowlin.

Location.—George Smith survey; 805 feet FSL, 770 feet FWL; 1½ mi. SW of Camp Verde.

Elevation.—1,680 feet, derrick floor; 1,670 feet, ground. *Total depth.*—7,902 feet. *Completed.*—1954.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—A scout card reported top of Marble Falls at 4,626 feet and top of Ellenburger "around 4,800 feet." Barnes (1959) reported top of Ellenburger at 5,320 feet. Apparently, this well penetrated foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1959, p. 470).

County.—Kerr.

Additional well not shown on map (Pl. 2) and not studied because of lack of samples or basic data:

G. L. ROWSEY No. 1 ELDER HENDERSON LEWIS ET AL.—

Location: J. E. Bellner survey; 1,971 feet FSL, 330 feet FWL; 1½ mi. NW of Camp Verde. *Elevation:* 1,640 feet. *Total depth:* 4,756 feet.

County.—Kinney.

Well name.—Austral Oil Exploration Company, Incorporated, No. 1-A Wardlaw-Whitehead Estate.

Location.—Melton Valdez Grant; 23,660 feet FNWL, 13,550 feet FSWL.

Elevation.—1,049 feet. *Total depth.*—4,378 feet. *Completed.*—1953.

Top of metamorphic rocks.—4,110 feet. *Elevation of metamorphic rocks.*— −3,061 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 4202–17.

Description of metamorphic rocks.—The single sample examined is a graphitic sericite slate showing well-developed foliation and slaty cleavage; metamorphism is low grade with a high shearing element. A sample log shows that the sequence is composed of interlayered slate and metaquartzite.

This well penetrated sheared metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Karl Schneidau, Austral Oil Exploration Company, Incorporated, 1954 (with sample description and electric log).

County.—Kinney.

Well name.—Fish Production Corporation No. 1 Roy Henderson.

Location.—Section 53, block 11, I&GN survey; 600 feet F most E'ly WL, 660 feet F most N'ly NL; 14 mi. N. 20° W. of Brackettville.

Elevation.—1,588 feet. *Total depth.*—2,699 feet. *Completed.*—1951.

Top of Paleozoic rocks.—2,140 feet. *Elevation of Paleozoic rocks.*— −552 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 2150–60, 2210–20, 2230–40, 2320–30, 2440, 2470–80, 2630, 2689–90.

Description of Paleozoic rocks.—This well encountered pre-Cretaceous rocks intruded by andesite porphyry. According to a sample log, Cambrian beds were identified in this sequence. The intrusive rocks range from albite andesite porphyry to trachyte and rhyolite porphyry; all of the igneous rocks show extensive alteration, and large volumes of the groundmass are composed of chlorite, epidote, calcite, and secondary amphibole. The host rock is fine-grained, angular to subround, fairly well-sorted, hematitic feldspathic quartzitic quartz sandstone and metaquartzite variably metamorphosed by intrusions; some fragments show completely recrystallized quartz mosaic containing clusters of sericite. The age of the rocks is unknown, and samples are too scanty and alteration too advanced to determine facies. Probably the host rocks are upper Paleozoic. Metamorphism is of the contact type, static, without a high shearing element.

This well is north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. B. Souther, Pan American Petroleum Corporation, 1953.

County.—Kinney.

Well name.—Fish Production Corporation No. 1 Postell.

Location.—Salitha Banks survey; 3,600 feet FNL, 4,620 feet FEL; 12 mi. N. 30° E. of Brackettville.

Elevation.—1,586 feet. *Total depth.*—5,374 feet. *Completed.*—1952.

Top of Paleozoic rocks.—2,740 feet. *Elevation of Paleozoic rocks.*— −1,154 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 3200, 3770–80, 3938–50, 3980–90, 4680–90, 4910–20, 5370–71. BUREAU OF ECONOMIC GEOLOGY: 5170–80, 5250–60, 5280–90.

Description of Paleozoic rocks.—According to Goldstein (1955), the pre-Cretaceous section can be divided into five units, from the top down: (1) conglomeratic arkose and black shale, (2) fossiliferous and siliceous limestone of Atokan age, (3) sandy limestone and sandy dolomite, (4) dolomitic sandstone and sandy dolomite, (5) weakly metamorphosed sandstones and carbonate rocks. He classified the sequence as normal foreland facies which has undergone local thermal metamorphism from a nearby igneous intrusion. Farmer (1957) reported a normal section including Atoka, Marble Falls, Ellenburger, and Cambrian with the Cambrian section correlative with the Llano uplift Cambrian section; base of Cretaceous, 2,732 feet; top of Ellenburger, 4,200 feet; top of Cambrian, 4,450 feet.

This well presents problems in interpretation. Metamorphism—of a static thermal or hydrothermal type without pronounced shearing—is variable in certain intervals. The clastic rocks (Atoka) in the upper part of the sequence are coarse-grained, angular, poorly sorted, feldspathic quartz sandstones or arkoses containing abundant fragments of metamorphic rock (muscovite schist); they were probably derived from a metamorphic terrane immediately to the south and as such support the position of the Luling front as drawn in this area (Pl. 2). Metamorphism is not the same kind that characterizes rocks of the Ouachita belt in this area and is probably due to local intrusions of igneous rock which are known in the area but do not appear in this boring. Except for the abundance of metamorphic detritus in the upper part of the sequence, the rocks penetrated in this well appear to be of normal foreland facies—the well is located north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: R. E. Farmer, Shell Oil Company, 1957; August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Kinney.

Well name.—Havoline Oil Company (Haveline, Havolind, Havolien) No. 1 Weatherby (Weatherbee).

Location.—Section 21, block 5, I&GN survey; 500 feet FNL, 2,640 feet FEL; 14 mi. NE of Del Rio.

Elevation.—1,220 feet. *Total depth.*—4,398± feet. *Completed.*—1927.

Top of Paleozoic rocks.—2,010 feet. *Elevation of Paleozoic rocks.*— −790 feet.

Top of metamorphic rocks.—4,381± feet. *Elevation of metamorphic rocks.*— −3,161± feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 4450. BUREAU OF ECONOMIC GEOLOGY: 2088–2103, 2340, 2350, 4400 (3).

Description of Paleozoic and metamorphic rocks.—Sellards (1933) described the rock as altered shale. According to Kleihege (1949) the section is composed mostly of gray crystalline dolomite with subordinate quartzite; the quartzites show sutured contacts and wavy extinctions. Rocks from the bottom of the hole are pale green schist. Sample descriptions in the Bureau of Economic Geology files indicate that the pre-Cretaceous sequence is mostly dark quartzitic dolomite and dolomitic quartzite with minor sandstone to a depth of 4,000 feet. "Rock salt" is reported from 4,000 to 4,057 feet, where a hard siliceous carbonate rock was encountered. The alleged presence of salt in this sequence is anomalous, and unfortunately samples from the interval are not available.

This well passes from Cretaceous rocks into a sequence of quartzitic dolomites and quartzites showing varied amounts of incipient to weak metamorphism; sample coverage is poor but a similar section in the nearby No. 1 Martin Rose (p. 286) contains sparse fossil remnants that indicate an early Paleozoic age (Ellenburger?) (Wilson, 1958). The No. 1 Weatherby bottoms in a highly sheared rhyolite (the pale green schist of Kleihege) which is partly mylonitized (phyllonitized)—the potassium feldspar is nearly all converted to sericite except for a few remnant phenocrysts; the rock resembles Precambrian metarhyolite exposed to the northwest in the Van Horn area and is probably Precambrian.

The well is located on the Devils River uplift, a structurally high area of Precambrian rocks, immediately north of overthrust metamorphic rocks of the interior zone of the Ouachita structural belt (Pl. 2). This allochthonous plate of metamorphic rocks has overridden foreland facies sedimentary rocks (see Magnolia No. 1 Wardlaw, p. 285). In the area of the No. 1 Weatherby the Paleozoic foreland carbonate rocks lying on the Precambrian metarhyolite show the effects of incipient to weak metamorphism. Probably this extension of metamorphism into foreland facies rocks was caused by the advance of the Ouachita belt against the resistant Devils River uplift.

X-ray data.—None.

References.—Kleihege (1949, pp. 34–35); Sellards (1933, p. 190).
Bureau of Economic Geology files.
Personal communication: J. E. Galley, Shell Oil Company, 1956; E. J. Theessen, Shell Oil Company, 1956; J. L. Wilson, Shell Development Company, 1957, 1958.
Incomplete samples are in Bureau of Economic Geology Well Sample Library.

County.—Kinney.

Well name.—Josey, Incorporated, No. 1 A. F. Beidler.

Location.—Melton Valdez survey; 6,400 feet FNEL of GH&SA survey, 2,450 feet FSEL of M. Valdez survey.

Elevation.—1,043 feet. *Total depth.*—4,006 feet. *Completed.*—1952.

Top of metamorphic rocks.—3,760 feet. *Elevation of metamorphic rocks.*— -2,717 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 3760–70, 3780–90, 3790–00, 3800–10, 3830–40, 3840–50, 3890–00, 3940–50, 3970–80, 3980–90, 3990–00. BUREAU OF ECONOMIC GEOLOGY: 3990–00, 4000–06.

Description of metamorphic rocks.—There are two interpretations of the sequence encountered in this well: (1) base of Cretaceous and top of Ordovician (Ellenburger), 3,760 feet; top of Hickory, 3,890 feet; top of Precambrian, 3,920 feet; or (2) base of Cretaceous and top of metamorphic rocks, 3,920 feet. The section in question is composed of beds of fine-grained inequigranular dolomite, sandy at the base, which lie on a metaquartzite sequence. The dolomite and basal sand show no signs of metamorphism; some geologists believe these beds are Ellenburger and some consider them basal Cretaceous. The correct answer is important because if they are Ellenburger, it means that the underlying metamorphic rocks are Precambrian, but if the dolomite is Cretaceous, the underlying metamorphic rocks could well be displaced metamorphic rocks of the Ouachita structural belt. Therefore, in order to map the correct position of the Ouachita front in this area, it is necessary to resolve the problem of the dolomite sequence. In the writer's opinion, the Cretaceous probably rests directly on metamorphic rocks in this well and there are no intervening Paleozoic beds.

The metaquartzite is a highly sheared low-grade metamorphic rock which is partly mylonitized in one sample; locally, it is sericitic and dolomitic. Structures are foliation and grain-stretching.

This well is tentatively considered to have penetrated the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: R. E. Farmer, Shell Oil Company, 1957; J. B. Souther, Pan American Petroleum Corporation, 1953.

County.—Kinney.

Well name.—Magnolia Petroleum Company No. 1 C. B. Wardlaw.

Location.—Melton Valdez survey; 2,640 feet FSL, 2,640 feet FWL; 16 mi. W of Brackettville.

Elevation.—998 feet; 988(?) feet. *Total depth.*—5,280 feet. *Completed.*—1931.

Top of metamorphic rocks.—3,430 feet. *Elevation of metamorphic rocks.*— -2,432 feet.

Top of Paleozoic rocks.—5,050(?) feet. *Elevation of Paleozoic rocks.*— -4,052(?) feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEM CORPORATION: 3440, 3450, 3510, 3840, 4220, 4290, 4300, 4300–10, 4310–20, 4315, 4320, 4715, 4960, 4960–61, 4985, 5235. BUREAU OF ECONOMIC GEOLOGY: 4202–07.

Description of Paleozoic and metamorphic rocks.—Goldstein (1955) reported base of Cretaceous and top of altered Paleozoic (Ordovician?), 3,450 feet; top of dolomite, 5,050 feet; total depth 5,280 feet, in dolomite; two igneous intrusive bodies were encountered in the metamorphosed sequence above the dolomite at 4,290 to 4,330 feet and 4,960 to 4,990 feet. He noted that the unaltered dolomite section is generally referred to as Ellenburger of normal foreland facies. P. S. Morey (sample log) logged top of metamorphic rocks at 3,430 feet and top of dolomite marble at 5,020 feet. Sellards (1933) reported top of Paleozoic at 3,450 feet and remarked that the well passed through more or less altered rock from 3,450 to near 5,050 feet, entered unaltered Ellenburger facies, and terminated at 5,280 feet.

The metamorphosed sequence is composed of schistose marbles, commonly sericitic, chloritic, and graphitic, and interlayered graphitic or hematitic sericite phyllite; metamorphism is low grade, fabrics range from porphyroblastic and poikiloblastic to cataclastic, structures are foliation and dimensional grain orientation. The intrusive rock is microgabbro, partly sericitized, and largely replaced by calcite; it shows no signs of metamorphism. The bottom samples are fine-grained equigranular dolomite, not metamorphosed.

The following structural history is suggested: (1) thrusting of metamorphosed Ouachita rocks over unmetamorphosed lower Paleozoic rocks of carbonate foreland facies; (2) intrusion of gabbroic rocks. This well penetrated the interior zone of the Ouachita belt. Minimum displacement on the overthrust is 6 to 8 miles.

X-ray data.—None.

References.—Goldstein and Reno (1952, p. 2286); P. S. Morey, Bureau of Economic Geology sample log; Sellards (1933, p. 189).

Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Kinney.

Well name.—Mud Creek Oil and Gas Company No. 1 J. O. Taylor.

Location.—½ mi. N of Amanda Siding, 2 mi. W of Standart.

Elevation.—1,100 feet (from topographic map). *Total depth.*—2,798 feet. *Completed.*—1919.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic or metamorphic rocks.—Notes in the files of the Bureau of Economic Geology report Cretaceous rocks at 2,688 feet and splintery blue-black shale at 2,798 feet, total depth. From its location, this well is probably in a structurally complex zone close to or within the Ouachita front.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Kinney.

Well name.—George Proctor No. 1 Wardlaw-Whitehead.

Location.—Melton Valdez survey; 19,100 feet FSEL, 19,800 feet FSWL; 5,800 feet NW of Pinto Creek, 1,160 feet SW of Southern Pacific Railroad.

Elevation.—1,070 feet, derrick floor. *Total depth.*—4,507 feet. *Completed.*—1948.

Top of metamorphic rocks.—4,090(?) feet. *Elevation of metamorphic rocks.*— -3020(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3095–3105, 3400–10, 3500–06, 3600–08, 3701–05, 3800–02, 3894–3907, 4090–4107, 4302–05.

Description of metamorphic rocks.—Cuttings from this well are very fine grained. The well is in rocks of the Ouachita belt at 4,090 feet. Samples are composed of fragments of (1) fine-grained, sheared, graphitic sericitic chloritic dolomitic metaquartzite or high rank metasandstone; (2) sericitic and chloritic microgranular metachert, locally graphitic and dolomitic; and (3) fine-grained siliceous sericitic metadolomite. Between 3,400 and 4,090 feet the cuttings are a mixture of Cretaceous limestone, locally sandy and silty, quartz grains (probably derived from sandstone), chert, and dolomite of unknown age, and fragments of metasandstone and clay shale apparently derived from the Ouachita belt. Either there has been some mixing of the samples or the Ouachita fragments occur as sand grains and pebbles in younger rocks.

The rocks of the Ouachita belt have been subjected to weak to low-grade high-shear metamorphism; they are similar to rocks of the interior zone penetrated in other Kinney and Val Verde County wells.

X-ray data.—None.

References.—None.

County.—Kinney.

Well name.—Richardson Oil Company No. 1 Martin Rose.

Location.—Block 5, I&GN survey; 600 feet NE of Havoline No. 1 Weatherby.

Elevation.—1,225 feet. *Total depth.*—2,675 feet. *Completed.*—1956.

Top of Paleozoic rocks.—1,959 feet. *Elevation of Paleozoic rocks.*— -734 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2593–2664 (5).

Description of Paleozoic rocks.—The pre-Mesozoic rocks are quartzose dolomite and dolomitic quartzitic metasandstone showing varying degrees of incipient to weak metamorphism. According to Wilson (1956, 1958), fossil fragments found in cores indicate a Paleozoic age, probably early Paleozoic; a gastropod fragment was identified as Ordovician.

Metamorphism in this sequence is not as intense as that to the south. In all probability these are early Paleozoic foreland facies carbonate rocks weakly metamorphosed by the thrust of the Ouachita belt against a local Precambrian buttress (cf. Havoline No. 1 Weatherby, p. 284). The well is located immediately north of allochthonous metamorphic rocks of the interior zone of the Ouachita belt (Pl. 2).

X-ray data.—None.

References.—Personal communication: E. J. Theessen, Shell Oil Company, 1956; J. L. Wilson, Shell Development Company, 1956, 1958.

Core chips are in Bureau of Economic Geology Well Sample Library.

County.—Lamar.

Well name.—Bailey Development Company No. 1 Alex Ford.

Location.—Parker S. Doss survey; 9 mi. S, 8 mi. W of Paris.

Elevation.—565 feet. *Total depth.*—1,930 feet. *Completed.*—Before 1925.

Top of Paleozoic rocks.—1,880 feet. *Elevation of Paleozoic rocks.*— -1,315 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1912–17 (2).

Description of Paleozoic rocks.—Sample descriptions in the Bureau of Economic Geology files report dark gray quartzitic sandstone and hard black slaty shale from 1,880 to 1,900 feet. Miser and Sellards (1931, p. 812) reported that cuttings below 1,880 feet are either Stanley shale or a shale and quartzite formation of Ordovician age. Thin section examination of the single sample available shows fine-grained, angular poorly sorted, slightly feldspathic quartz sandstone and dark shale; probably these rocks are Stanley but no unequivocal determination can be made from one sample.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Miser and Sellards (1931, pp. 812–813); Sellards (1933, p. 190).
Bureau of Economic Geology files.
Incomplete samples are in Bureau of Economic Geology Well Sample Library.

County.—Lamar.

Well name.—Clark and Ogg No. 1 Smiley.

Location.—T. M. Clark survey; 330 feet FNL, 330 feet FEL; 3 mi. N of Brookston.

Elevation.—582 feet. *Total depth.*—3,351 feet. *Completed.*—1944.

Top of Paleozoic rocks.—3,195 feet. *Elevation of Paleozoic rocks.*— -2,613 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 3261, 3274–76, 3295, 3305, 3320, 3335.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous (Trinity) and top of Paleozoic Ouachita facies at 3,195 feet; total depth 3,351 feet, in Paleozoic rocks.

The upper part of the sequence is light to very dark brown cryptocrystalline to microgranular chert, locally argillaceous, and commonly fractured and veined with quartz; small spherical lighter colored siliceous bodies (radiolarians?) are common. The chert is underlain by dark chloritic sideritic(?) metashale or clay-slate veined with quartz-chlorite. The bottom sample is fine-grained, angular, very poorly sorted, micaceous argillaceous silty quartz sandstone.

The very weakly metamorphosed chert-metashale sequence is pre-Stanley Ouachita facies—probably Bigfork-Womble. The unit encountered at the bottom of the hole resembles Stanley and there is, therefore, a possibility of overthrusting or an inverted section in this well.

This well penetrated the frontal zone of the Ouachita belt in the projected southwestern extension of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Lamar.

Well name.—Cosden Petroleum Company No. 1 W. T. Adams.

Location.—J. H. Gibson survey.

Elevation.—511 feet. *Total depth.*—3,065 feet. *Completed.*—1944.

Top of metamorphic rocks.—2,820 feet. *Elevation of metamorphic rocks.*— -2,309 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 2820, 2835, 2860, 2865, 2890, 2895, 3035.

Description of metamorphic rocks.—Goldstein (1955) reported base of Cretaceous and top of Ouachita facies Paleozoic (Blaylock?), 2,820 feet; total depth 3,065 feet, in Blaylock(?).

The sequence is composed of fine-grained chloritic sericitic metaquartzite, locally pyritic and dolomitic, chlorite slate, and chlorite-sericite slate or phyllite cut by chlorite-quartz-carbonate veinlets. Reconstitution is complete; metamorphism is weak to low grade.

This well penetrated the southwestern subsurface extension of the Broken Bow—Benton uplift of the Ouachita Mountains; the rocks are weakly metamorphosed lower Paleozoic beds of Ouachita facies.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Lamar.

Well name.—Doyle and Jondreau No. 1 Joe Horn (Martin).

Location.—R. P. Mayo survey; 2,200 feet FNL, 1,000 feet FEL; 12 mi. NE of Paris.

Elevation.—532 feet. *Total depth.*—2,958 feet. *Completed.*—1932.

Top of Paleozoic rocks.—2,860 feet. *Elevation of Paleozoic rocks.*— -2,328 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2860-80 (2).

Description of Paleozoic rocks.—Notes in the Bureau of Economic Geology files report white and gray indurated siliceous rock with a schist-like character.

Paleozoic rocks are dark cryptocrystalline to microgranular argillaceous chert and dark slightly silty shale or metashale.

On the basis of lithology and location, this well appears to have penetrated incipiently metamorphosed lower Paleozoic Ouachita facies rocks in the southwestern subsurface extension of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Bureau of Economic Geology files.

Personal communication: B. W. Fox, The Atlantic Refining Company, 1957; H. A. Sellin, Magnolia Petroleum Company, 1957.

County.—Lamar.

Well name.—A. T. Walker et al. No. 1 Federal Land Bank.

Location.—A. T. Norwell survey; 5½ mi. N of Blossom.

Elevation.—501 feet. *Total depth.*—2,685 feet. *Completed.*—Before 1937.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2680–85.

Description of Paleozoic or metamorphic rocks.—Barnes (Bur. Econ. Geol. files) described a core from 2,680 to 2,685 feet as a phyllite containing small porphyroblasts and noted that metamorphism is not extreme; cleavage dips at a low angle. The single sample available is light-colored argillaceous microspherulitic chert and siliceous metashale or clay-slate containing "porphyroblasts" of dark "pleochroic" carbonate and sporadic grains of quartz sand; metamorphism is very weak. These rocks are lower Paleozoic rocks of Ouachita facies, possibly Arkansas novaculite. This well penetrated the southwestern subsurface projection of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Lampasas.

Well name.—Mark Alexander et al. No. 1 Alexander Brothers.

Location.—S. Berry survey; 6 mi. SE of Lampasas.

Elevation.—1,025 feet. *Total depth.*—ni. *Completed.*—Before 1932.

Top of Paleozoic rocks.—1,000 feet. *Elevation of Paleozoic rocks.*— +25 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sellards (1933) recorded top of Ordovician at 1,000 feet. This well apparently penetrated foreland rocks west of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1933, p. 216).

A single sample is in Bureau of Economic Geology Well Sample Library.

County.—Lee.

Well name.—Skelly Oil Company and Sunray Midcontinent Oil Company No. 1 Cornell.

Location.—Albert Nantz survey; 6,800 feet FNEL, 2,550 feet FSEL; approx. 8,900 feet F Williamson County line, 12,400 feet F Bastrop County line.

Elevation.—534 feet, derrick floor; 523 feet, ground. *Total depth.*—6,826 feet. *Completed,*—1957.

Top of metamorphic rocks.—6,610 feet. *Elevation of metamorphic rocks.*— -6,076 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 6745–50.

Description of metamorphic rocks.—The sequence is composed of dark graphitic chlorite-sericite phyllite cut by numerous quartz veins; graphitic material is concentrated along shear planes. Structures are foliation, well-developed fracture cleavage, crinkling and rucking; metamorphism is low grade with a strong shearing element.

This well penetrated the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: K. H. Hamilton, Skelly Oil Company, 1957.

County.—Limestone.

Well name.—Farrell Drilling Company No. 1 J. R. Gillam.

Location.—J. S. Spencer survey; 1,536 feet FNWL, 1,426 feet FNEL; 2 mi. E of Mart.

Elevation.—521 feet. *Total depth.*—4,867 feet. *Completed.*—1941.

Top of metamorphic rocks.—4,750 feet. *Elevation of metamorphic rocks.*— -4,229 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 4185, 4245, 4305, 4365, 4385, 4425, 4475, 4485, 4600–4760, 4615, 4685, 4760–4869, 4765, 4835, 4860. BUREAU OF ECONOMIC GEOLOGY: 4860–70.

Description of metamorphic rocks.—The sequence in this well consists of highly sheared sericite-chlorite phyllite and sericitic metaquartzite; in the phyllite, porphyroblasts of muscovite are oriented parallel to and at right angles to the foliation. Metamorphism is low grade with a high shearing element. Goldstein and Reno (1952, p. 2281) figured a photomicrograph of a core fragment from 4,867 feet as "meta-argillite."

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—I (100%); SR = 5.5. Mica is well crystallized.

References.—Goldstein and Reno (1952, p. 2281).
Personal communication: B. W. Fox, The Atlantic Refining Company, 1956; August Goldstein, Jr., Pan American Petroleum Corporation, 1955; H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—Limestone.

Well name.—Pure Oil Company No. 16-T W. H. Kendricks.

Location.—Mexia field.

Elevation.—519 feet. *Total depth.*—8,284 feet. *Completed.*—1937(?).

Top of metamorphic rocks.—8,235± feet. *Elevation of metamorphic rocks.*— -7,716± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 8233–38 (2), 8251–59, 8278–84.

Description of metamorphic rocks.—Barnes (Bur. Econ. Geol. files) described the sequence as composed of unmetamorphosed shales and sandstones overlying a chloritic quartzite (8,233 to 8,238-foot interval). Turner (1957) reported total depth in the Smackover formation.

Available samples are fine to coarse-grained, angular, poorly sorted, siliceous graywacke composed of abundant fragments of sheared sericite-chlorite phyllite, sericitic metachert, vein quartz, microlitic igneous rock, quartz, feldspar, mica and chlorite cemented by silica. In some fragments the calcite and dolomite cement has partly replaced the rock fragments.

The rocks studied appear to be late Paleozoic or Mesozoic clastic rocks derived from the Ouachita belt and in large part from the interior zone of metamorphic rocks. According to Barnes (above), rocks of the interior zone of the Ouachita belt were encountered beneath the deepest samples available for study (8,284 feet).

X-ray data.—None.

References.—Bureau of Economic Geology files.
Personal communication: G. L. Turner, Pure Oil Company, 1958.

County.—Limestone.

Well name.—The Texas Company No. 1 Keeling.

Location.—Alex Whitaker survey; 6½ mi. SW of Coolidge.

Elevation.—546 feet. *Total depth.*—6,018 feet. *Completed.*—1942.

Top of metamorphic rocks.—6,000 feet. *Elevation of metamorphic rocks.*— -5,454 feet.

Thin section coverage (depth in feet).—None.

Description of metamorphic rocks.—Goldstein (1955) reported top of Paleozoic at 6,000 feet; samples are described from 6,004 to 6,007 feet and classified by Goldstein as chlorite-sericite metaquartzites containing swarms of opaque needles (rutile altered to leucoxene?). He noted that these rocks are similar to metasedimentary rocks from the Luling field and that they are possibly a metamorphosed equivalent of the Blaylock formation.

This well penetrated metamorphosed rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Maverick.

Well name.—Humble Oil & Refining Company No. 1 Bandera County School Land.

Location.—Bandera County School Land survey; 660 feet FSL, 660 feet FEL; 19 mi. NE of Eagle Pass.

Elevation.—909 feet. *Total depth.*—13,863 feet. *Completed.*—1956.

Top of metamorphic rocks.—13,332(?), 13,462(?) feet. *Elevation of metamorphic rocks.*— -12,-423(?), -12,553(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 7890–7920, 8570–8600, 8600–04, 10,140–70 (2), 11,460–70 (8), 11,590–93, 12,362–72, 13,306–09, 13,329–32½, 13,332–35, 13,478–81, 13,481–84 (2), 13,478–500, 13,500–03, 13,523–28, 13,552–55, 13,594–97, 13,700–03, 13,730–33, 13,781–84, 13,800±(?), 13,828–31, 13,865–67.

Description of metamorphic rocks.—Woods (1957) reported base of Jurassic(?) and top of "basement" at 13,462 feet. Cores in the Bureau of Economic Geology Well Sample Library indicate that the top of the metamorphic sequence is at 13,332 feet, considerably higher than the figure given by Woods; possibly the cores are incorrectly labeled. The metamorphosed section in this well is overlain by hard red to maroon conglomerate and shale of unknown age; the conglomerate contains abundant fragments of metamorphic rocks—phyllite, schist, metaquartzite—and vein quartz.

Petrographic study shows the upper clastic rocks are (1) dark reddish fine- to medium-grained, angular to round, fairly well-sorted to poorly sorted, hematitic calcareous or dolomitic feldspathic micaceous quartz sandstone commonly quartzitic, containing abundant fragments of chert and slate-phyllite, commonly veined by calcite, less commonly by fine quartz; (2) dark red, hematitic calcareous conglomerate; and (3) dark red, hematitic quartz siltstone. The conglomerate is composed of low-grade metamorphic rock fragments (slate, phyllite, schist, metaquartzite) which commonly show evidence of strong shearing, chert, sandstone, metasandstone, vein quartz, and feldspar in a matrix of quartz-feldspar silt-sand, micaceous matter, and sparry calcite. The rock fragments appear to have been derived from the Ouachita structural belt. One sample contains a pebble of cataclastically altered sericitized muscovite granite—indicating the presence of pre-deformation granite in the structural belt. Fine-grained silty calcilutite is present in the 8,600 to 8,604-foot interval.

Beneath the clastic sequence is interlayered dark sericite-chlorite slate (locally siliceous, hematitic, graphitic) and dark chloritized spilitic basalt or greenstone, locally strongly sheared. Quartz and calcite veins, both pre- and post-deformation, are abundant. The slate, well foliated, is apparently greenstone completely altered by shearing and hydrothermal metamorphism—the plagioclase is converted to sericite. The greenstone shows a relict porphyritic-subophitic fabric; where strongly sheared, the plagioclase laths are cataclastically re-oriented and the phenocrysts are shattered. Shearing in the greenstone is clearly shown in the calcite and quartz veins which are stretched and deformed. Metamorphism is weak with strong shearing and metasomatic elements; structures are foliation, microfolding, contortion.

This well penetrated a strongly sheared sequence of volcanic rocks in the interior zone of the Ouachita belt. Similar rocks were encountered to the east in wells that penetrated the black slate belt (Humble No. 1 Wilson, Medina County; General Crude No. 1 Rogers Ranch, Bexar County).

X-ray data.—None.

References.—Personal communication: R. D. Woods, Humble Oil & Refining Company, 1957, 1958. Cores are in Bureau of Economic Geology Well Sample Library.

County.—McLennan.

Well name.—Daniel Oil Company No. 1 Elizabeth W. Estes.

Location.—Duke Faulkner survey; 1½ mi. W of Lorena.

Elevation.—580 feet. *Total depth.*—2,671 feet. *Completed.*—1949.

Top of Paleozoic rocks.—1,745 feet. *Elevation of Paleozoic rocks.*— -1,165 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1735, 2400, 2468, 2598 (2), 2650 (2).

Description of Paleozoic rocks.—According to a scout report, a core (2,551 to 2,556 feet) recovered quartzitic sandstone with streaks of black limestone.

The upper part of the sequence is composed of fine-grained, angular to subround, poorly to fairly well-sorted, feldspathic quartz sandstone containing a high percentage of garnet in the heavy mineral fraction, fine-grained quartz siltstone with streaks and layers of locally deformed dark shale, and layers of cone-in-cone limestone; quartz and calcite veins are common. These rocks are Stanley. In the 2,598-foot interval there is a very dark argillaceous dolomitic chert or siliceous shale containing dark

organic matter that suggests Bigfork lithology; the 2,650-foot sample is fine-grained dolomitic limestone containing a small amount of dark organic material and also may be Bigfork.
This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1956; H. A. Sellin, Magnolia Petroleum Company, 1956.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—McLennan.

Well name.—Delta Drilling Company (Carpenter and Clements) No. 1 C. Horstman.

Location.—B. C. Walters survey; 2,900 feet FSWL, 3,700 feet FSEL; 1 mi. SE of McGregor.

Elevation.—695 feet. *Total depth.*—2,259 feet. *Completed.*—1939.

Top of Paleozoic rocks.—1,120 feet. *Elevation of Paleozoic rocks.*— -425 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1130–40, 1195–98 (2), 1391–96, 1620–35, 1785–90, 2247–59.

Description of Paleozoic rocks.—The sequence is composed of dark argillaceous dolomitic cryptocrystalline chert containing dark organic material, dark siliceous argillaceous dolomite, and dark argillaceous spiculitic dolomitic limestone; the carbonate rocks are all very finely crystalline. This section is identified as Bigfork chert. In the middle of the Bigfork sequence (1,620 to 1,625 feet) there is a fine-grained angular poorly sorted feldspathic quartz sandstone containing angular slivers of garnet among the heavy minerals; it is a typical Stanley sandstone. The general area is one of structural complexity, and the presence of a slice of Stanley sandstone within a Bigfork sequence can be explained by folding or faulting; an alternative explanation is sample mixing or contamination.
This well penetrated lower Paleozoic Ouachita facies rocks close to the front of the Ouachita belt in an area of probable overthrusting.

X-ray data.—None.

References.—Personal communication: G. L. Turner, Pure Oil Company, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—McLennan.

Well name.—Falcon Oil Company No. 1 H. Mattlage.

Location.—E. C. Woodruff survey; 330 feet FSL, 330 feet FEL; 5 mi. NW of Crawford.

Elevation.—767 feet, kelly bushing; 750 feet, ground. *Total depth.*—7,585 feet. *Completed.*—1954.

Top of Paleozoic rocks.—1,072 feet. *Elevation of Paleozoic rocks.*— -305 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1100–10, 1200–10 (2), 1290–00 (3), 2510–20, 3270–80, 3430–40, 3500–10, 4440–50, 4710–20 (2), 5000–10 (2), 6010–20 (2), 6500–10, 6850–60, 6880–90, 6950–60, 7000–10, 7430–40, 7580–90.

Description of Paleozoic rocks.—The Paleozoic sequence in this well is divided into three units. The upper unit is dark silty shale and fine- to coarse-grained, angular to subround, poorly to fairly well-sorted, commonly calcareous, locally argillaceous quartz sandstone, some of which is quartzitic; locally the sandstones and shales contain traces of glauconite. These rocks are probably Atoka although the clay mineralogy is not typically Atoka. Underlying the Atoka(?) is a black calcareous shale containing calcareous and siliceous spicules and pelmatozoan debris; this is Marble Falls—Barnett lithology. The lower unit, topped at 6,870 feet, is fine-grained equigranular dolomite and limestone of the Ellenburger group. Because of incomplete sample coverage, the top of Marble Falls—Barnett rocks cannot be determined with certainty.
This well penetrated foreland rocks a short distance west of the Ouachita belt.

X-ray data.—1,200 feet: I $>$ Ch; 10/7 $\sim$ 1; F $=$ 20; SR $=$ 3.45 (probably not Atoka).

References.—Personal communication: G. L. Turner, Pure Oil Company, 1957, 1958; and sample log.

County.—McLennan.

Well name.—Hodges et al. No. 1 Lawrence.

Location.—B. C. Walters survey; "near" McGregor.

Elevation.—438 feet. *Total depth.*—ni. *Completed.*—Before 1931.

Top of Paleozoic rocks.—1,313(?) feet. *Elevation of Paleozoic rocks.*— -875(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1330–35 (2), 1600.

Description of Paleozoic rocks.—Descriptions in the Bureau of Economic Geology files report samples 1,313, 1,322, and 1,330 to 1,335 feet are hard black shale with some dolomite fragments, and sample 1,600 feet is chert, green shale, and dolomite, possibly Bigfork; top of Paleozoic is not given; top of Trinity is reported as 985 feet.

Sellards (1931b, p. 823) described the sequence as chert and black shale and (p. 827) noted resemblance to Bigfork. Goldstein (1955) reported light-colored slightly calcareous cryptocrystalline cherts, some of which are argillaceous and contain radiolarians.

Thin section study shows the samples are green argillaceous cryptocrystalline chert and green to brown siliceous shale (1330–35) and darker cryptocrystalline dolomitic chert (1600). The lighter colored chert higher in the hole contains sporadic grains of rhombic "pleochroic" carbonate—dolomite or siderite. These rocks are interpreted as pre-Stanley Ouachita facies rocks; the darker cherts lower in the well may be Bigfork.

This well penetrated the frontal zone of the Ouachita structural belt near its western boundary, probably in an area of overthrusting.

X-ray data.—None.

References.—Sellards (1931b, pp. 823, 827).
Bureau of Economic Geology files.
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—McLennan.

Well name.—Korshoj No. 1 Simon-Ferguson.

Location.—A. R. Valdez survey; 520 feet FSWL, 2,340 feet FNWL; 2 mi. N of Axtell.

Elevation.—570 feet. *Total depth.*—4,378 feet. *Completed.*—1954.

In Paleozoic rocks.—3,200 feet. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3200–10 (2), 3300–10, 3400–10, 3500–10, 3600–10 (2), 3700–10 (2), 3800–10 (2), 4000–10 (2), 4200–10 (2), 4350–60.

Description of Paleozoic rocks.—This well penetrated at least 1,150 feet of gray micaceous dolomitic quartz metasiltstone and gray to black silty metashale or clay-slate; quartz, quartz-chlorite, and quartz-dolomite veins are common. Structures are microfolding, rucking, and shearing. The presence of small blebs of new chlorite and new mica fibers indicates very weak to weak metamorphism. This well penetrated weakly metamorphosed dark clastic rocks of unknown age in the interior part of the frontal zone.

X-ray data.—$I > Ch$; $10/7 \sim 0.4–1.5$; $F = 20$; $SR = 9.0$.

References.—Personal communication: H. J. Morgan, Jr., The Atlantic Refining Company, 1955.

County.—McLennan.

Well name.—J. L. Myers & Sons No. 1 Axtell City Water Well.

Location.—In the city of Axtell.

Elevation—528 feet. *Total depth.*—2,129 feet. *Completed.*—1959.

Top of Paleozoic rocks.—3,069 feet. *Elevation of Paleozoic rocks.*— –2,541 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3040–60, 3060–80, 3080–3100.

Description of Paleozoic rocks.—The rocks include dark red and green hematitic rutiliferous sericite-chlorite slate, veined with quartz and extensively sheared and sliced, and dark hematitic dolomitic sericitic chloritic metasiltstone veined with quartz.

This well penetrated weakly metamorphosed rocks along the boundary of the frontal and interior zones. The highly sheared rutiliferous slate is similar to rocks in the interior zone farther east; the metasiltstone resembles rocks of the dark clastic unit in the eastern part of the frontal zone in this area. Possibly the rocks have been tectonically mixed.

X-ray data.—None.

References.—Personal communication: H. D. Holloway, 1959.

County.—McLennan.

Well name.—Muth and Berry No. 1 Freeman (also known as Freeman and Butler).

Location.—R. Simpson survey; 2½ mi. S of Valley Mills.

Elevation.—732 feet. *Total depth.*—ni. *Completed.*—1950.

Top of Paleozoic rocks.—1,120 feet. *Elevation of Paleozoic rocks.*— –388 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1200–10, 1880–90.

Description of Paleozoic rocks.—H. J. Plummer (Bur. Econ. Geol. files) described the following sequence; 1,120 to 1,190 feet, red, red-brown, and gray shale, probably a weathered surface; 1,190 to 1,380 feet, hard dark carbonaceous shale and silty shale; 1,380 to 2,000 feet, hard dark shale and hard gray sandstone or siltstone.

Petrographic study of two samples shows dark silty shale and fine-grained, mostly subangular, fairly well-sorted, slightly argillaceous and dolomitic quartz sandstone; the rocks are cut by dolomite and bitumen-pyrite veinlets. The sandstone contains fragments of metasiltstone and dark siliceous shale rich in organic material (Bigfork?) evidently derived from the Ouachita belt to the east.

This well penetrated Atoka beds immediately west of the Ouachita belt.

X-ray data.—$I > ML > Ch > K$; $10/7 \backsim 1.2$; $F = 20$; $SR = 1.50$.

References.—Bureau of Economic Geology files.

County.—McLennan.

Well name.—F. J. Ossenbeck No. 1 Charles Bezdek (Bezdak).

Location.—12 mi. N of Waco, 7 mi. SW of West.

Elevation.—570 feet (from topographic map). *Total depth.*—3,200± feet. *Completed.*—1921.

Top of Paleozoic rocks.—1,540 feet. *Elevation of Paleozoic rocks.*— -970± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Adkins (1923, pp. 134–136) included a driller's log and placed top of Pennsylvanian at 1,540 feet. He described the rocks (p. 26) as black shale, slate, and limestone, probably belonging to the Bend series.

From its location and the sample descriptions, this well probably penetrated Stanley shale.

X-ray data.—None.

References.—Adkins (1923, pp. 26, 134–136).

County.—McLennan.

Well name.—St. Louis Oil Pool Company No. 1 Ella V. Stuart (Stewart).

Location.—J. L. Johnston survey; NW corner; 2¾ mi. S, ½ mi. E of McGregor.

Elevation.—722 feet. *Total depth.*—3,512 feet. *Completed.*—1920.

Top of Paleozoic rocks.—1,235± feet. *Elevation of Paleozoic rocks.*— -513± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1940 (2), 2120, 2310, 2340–2660, 2380 (2), 2700 (3), 3340–3500.

Description of Paleozoic rocks.—Descriptions by J. A. Udden of scattered samples between 1,940 and 2,700 feet show black siliceous spiculitic limestone and chert, locally bituminous (Bur. Econ. Geol. files). Adkins (1923, p. 26) described the sequence as black shale, slate, and limestone, probably belonging to the Bend series and included a driller's log and sample descriptions by L. Pace (pp. 142–145). Sellards (1931) reported chert, limestone, and black shale. Goldstein (1955) described two samples: dark brown chert of the Bigfork formation (1,940 feet) and clay shale and glauconitic dolomite (3,348 to 3,500 feet).

The upper part of the Paleozoic sequence is dark argillaceous dolomitic cryptocrystalline chert containing dark organic material, locally spiculitic, of the Bigfork chert. Underlying the chert is dark slightly silty shale and fine- to medium-grained, slightly fossiliferous and pelletiferous, slightly glauconitic argillaceous dolomitic limestone of unknown age.

This well penetrated pre-Stanley rocks of Ouachita facies close to the western margin of the belt in an area of probable overthrusting. Possibly the carbonate rocks in the bottom part of the well are foreland rocks beneath a frontal overthrust, but sample coverage is too meager for a reliable identification.

X-ray data.—None.

References.—Adkins (1923, pp. 26, 142–145); Sellards (1931b, p. 823).
Bureau of Economic Geology files.
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—McLennan.

Well name.—Waco City Water Works Well.

Location.—First and Webster Streets, Waco, Texas.

Elevation.—ni. *Total depth.*—ni. *Completed.*—1914(?).

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2385.

Description of Paleozoic rocks.—Adkins (1923, p. 26), reporting on the possibility of Ordovician rocks in an old well at Waco, quoted E. G. Woodruff from a letter written to J. A. Udden in October 1919: ". . . Late in the fall of 1914 . . . I visited a well which was being drilled near the center of the town [Waco] . . . I procured a sample . . . from about 2,400 feet. Lithologically this appeared to be older than the Upper Paleozoics. As I remember the specimen, there were some fragmentary fossils in it. . . . some of the men of the United States Geological Survey . . . expressed the opinion that it was probably as old as Ordovician . . . I considered the evidence too imperfect to form a basis for scientific conclusion. . . . Personally I am inclined to think that the specimen came from Lower Paleozoic."

Adkins (letter to J. A. Udden, 1923) referred to Ordovician rocks found in the Waco well at First and Webster Streets and discussed the possibility that: (1) a strip of Ordovician rocks forms the pre-Cretaceous subcrop east of Waco and is in fault contact with Pennsylvanian beds to the west of Waco, or (2) there is an eroded uplift with Pennsylvanian beds stripped off in the area of Waco—Pennsylvanian beds thicken to the north (in the Ossenbeck well) and south (in the Stuart well).

A driller's log of this well and Udden's description of the samples (Adkins, 1923, pp. 153–154) extend only to a depth of 2,230 feet.

The single sample available for study is composed of fine fragments of light and dark-colored cryptocrystalline microgranular and microspherulitic chert some of which contains abundant red-brown organic material and round siliceous bodies (radiolarian tests?). Cross-cutting veinlets of quartz-bitumen are common. This chert is Bigfork type.

The well penetrated pre-Stanley Ouachita facies rocks (Bigfork) in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Adkins (1923, pp. 25–26, 153–154).
Bureau of Economic Geology files.

County.—McLennan.

Well name.—Waco Oil and Refining Company No. 1 G. H. Harrington.

Location.—M. Moore survey; 4½ mi. N of Waco.

Elevation.—486 feet. *Total depth.*—3,697 feet. *Completed.*—Before 1923.

Top of Paleozoic rocks.—2,215(?) feet; 2,114(?) feet. *Elevation of Paleozoic rocks.*— -1,729(?) feet; -1,628(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2600 (2), 2650 (3), 2660, 2670 (2), 2680 (2), 2730 (2), 3060, 3069, 3255, 3300–3495, 3315, 3425, 3435 (2), no depth given (7).

Description of Paleozoic rocks.—Adkins (1923, p. 26) reported top of Pennsylvanian (probably Bend) at 2,215 feet and noted that Udden described a sequence of arkosic quartzite, graphitic schist, and other ancient-looking rocks from 2,596 to 3,697 feet which he assigned to the Precambrian; a sample log by Udden and a driller's log are included (pp. 119–129). Sellards (1931b) placed the top of the Paleozoic at 2,600 feet and described the sequence as composed of quartzitic sandstone and black shale, probably of the Stanley-Jackfork formations. Barnes (*in* Sellards, 1933) described a single sample of quartzite from this well as composed of grains of quartz that have been largely recrystallized and much broken, and concluded that metamorphism is rather advanced.

The sequence in this well is fine-grained, angular, poorly sorted, feldspathic quartz sandstone, locally quartzitic, calcareous, argillaceous, micaceous, and dark metashale. The rocks show incipient to very weak metamorphism, and quartz grains in the sandstones are commonly fractured. There is general similarity to Stanley lithology.

This well penetrated incipiently to very weakly metamorphosed Stanley rocks in the eastern part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Adkins (1923, pp. 26, 119–129); Sellards (1931b, pp. 823, 826; 1933, p. 135).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Medina.

Well name.—California-Medina Association (also known as California-Medina Oil Company) No. 1 Rothe Estate.

Location.—Section 1012, Medina County School Land survey; 940 varas FWL, 1,440 varas FSL; 8 mi. NW of D'Hanis.

Elevation.—1,025 feet. *Total depth.*—3,705 feet. *Completed.*—1925.

Top of Paleozoic rocks.—2,616± feet. *Elevation of Paleozoic rocks.*— -1,591± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2616.

Description of Paleozoic rocks.—Sellards (1931b) described a core from the interval 3,560–3,565 feet as black shale. A note in the Bureau of Economic Geology files reports black shale at 3,144 feet. A single sample examined from 2,616 feet is angular tightly packed calcareous quartz siltstone.

On the basis of location and lithology, this well probably penetrated upper Paleozoic Ouachita facies rocks in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1931b, p. 822; 1933, p. 190).
Bureau of Economic Geology files.
Incomplete samples are in Bureau of Economic Geology Well Sample Library.

County.—Medina.

Well name.—R. E. Fair, Incorporated, No. 1 McAnelly.

Location.—E. C. Durst survey; 475 feet FWL, 370 feet FEL; 9 mi. W, 3 mi. N of Devine.

Elevation.—717 feet, derrick floor. *Total depth.*—5,512 feet. *Completed.*—1946.

***Top of Paleozoic rocks.*—5,427 feet. *Elevation of Paleozoic rocks.*— -4,710 feet.**

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 5425–27. BUREAU OF ECONOMIC GEOLOGY: 5425-27, 5438–41.

Description of Paleozoic rocks.—Only two samples from this well were examined. The rock in the interval 5,425 to 5,427 feet is massive siliceous hematite-calcite vein rock which gives little indication of the nature or facies of the country rock in the area. The 5,438 to 5,441-foot sample is dark-banded calcareous cryptocrystalline chert.

On the map (Pl. 2) the well falls in the black slate belt of the interior zone. In all probability the well penetrated the Ouachita belt somewhere close to the boundary between the frontal and interior zones. Samples are too meager to permit use of this well for geologic control.

X-ray data.—None.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1956.

County.—Medina.

Well name.—Humble Oil & Refining Company No. 1 E. E. Wilson.

Location.—AB&M survey; 1,980 feet FSL, 1,980 feet FEL; 6.4 mi. SW of Yancey.

Elevation.—725 feet, derrick floor. *Total depth.*—7,167 feet. *Completed.*—1949.

Top of metamorphic rocks.—6,980 feet. *Elevation of metamorphic rocks.*— -6,255 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 7068–70, 7161–62, 7163–66. BUREAU OF ECONOMIC GEOLOGY: 7065–68, 7162–63, 7163–66 (2).

Description of metamorphic rocks.—According to Masson (1954), the following rock types were logged in this well: 7,068 to 7,070 feet, granitic rock; 7,161 to 7,162 feet, dacite or andesite porphyry; 7,162 to 7,166 feet, altered dacite or andesite porphyry. Goldstein (1955) reported top of granite at 6,980 feet with total depth 7,167 feet in granite.

Thin section study shows that the rock in the 7,065 to 7,068-foot interval is a brecciated and cataclastically altered, medium-grained, biotite granite. Quartz and feldspar grains are fractured and broken apart; the plagioclase is partly sericitized; mica plates are locally bent; chlorite occurs as granular masses in breccia zones and as sheaves (after biotite); calcite is common in the brecciated parts of the rock. The intervals 7,162 to 7,163 and 7,163 to 7,166 feet are composed of fractured and altered andesite or dacite porphyry. The groundmass is a mass of plagioclase, epidote, and chlorite in which the outlines of relict feldspar microlites are visible; plagioclase phenocrysts are partly altered to epidote and chlorite; quartz is present as round embayed phenocrysts and as veinlets and secondary cavity fillings; prehnite occurs in cavities with quartz and also partly replaces plagioclase.

This well is located within the interior zone of the Ouachita belt. Similar rocks were encountered in the General Crude No. 1 Rogers Ranch, Bexar County, which also penetrated black slate (p. 224).

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; P. H. Masson, Humble Oil & Refining Company, 1954.

County.—Medina.

Well name.—John I. Moore No. 1 Alfred J. Wurzbach.

Location.—Juan Delgado survey; 4,500 feet FEL, 3,400 feet FNL; 5 mi. NE of Castroville.

Elevation.—1,011 feet. *Total depth.*—3,193 feet. *Completed.*—1945.

Top of Paleozoic rocks.—2,864 feet. *Elevation of Paleozoic rocks.*— –1,853 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 3160–70 (3), 3191–92 (2). BUREAU OF ECONOMIC GEOLOGY: 2874–76, 2879–81, 2886–98, 2950–60 (4), 3000–10 (4), 3050–60, 3070–80 (2), 3080–90, 3150–60, 3170–80 (2), depth unknown (2).

Description of Paleozoic rocks.—Goldstein (1955) reported that below the base of the Cretaceous at 2,852 feet, there are thin beds of hard massive dark gray micaceous shale, sandy shale, and sandstone to a depth of 2,885 feet. From 2,885 to 2,985 feet is a contact zone of sediments intruded and metamorphosed by serpentine-like igneous rock. Gray altered shale and very fine-grained dirty quartzitic sandstone were penetrated from 2,985 to 3,080 feet. Another mixed zone of altered sediments intruded by dikes and stringers of igneous material extends from 3,080 to 3,193 feet.

Thin section study shows a sequence of deformed and brecciated dark sandy and silty micaceous metashale and dark, fine- to medium-grained, mostly angular, poorly sorted, locally slightly glauconitic pyritic calcareous micaceous feldspathic argillaceous quartz sandstone extensively veined by calcite and quartz. The distinguishing characteristic of this sedimentary sequence is the presence of abundant plates of second-cycle reddish biotite. In the intervals 2,890–2,895, 2,950–2,960, 3,000–3,010, 3,080–3,090, 3,150–3,160, and 3,170–3,180 feet the samples contain fragments of cataclastically altered muscovite biotite granodiorite; fractured and broken grains of microperthite and albite are separated by zones of crushed quartz-feldspar-sericite-chlorite-calcite, and veins of sericite-chlorite-calcite are common. In the intervals 2,950 to 2,960 and 3,000 to 3,010 feet there are also fragments of trachyte porphyry and fragments of dark, fine-grained, locally fossiliferous, calcilutite veined by sparry calcite and quartz. A fragment of muscovite schist occurs at 2,890 to 2,895 feet and in the bottom part of the well there are abundant fragments of masses of sericite-chlorite. As an alternative to Goldstein's interpretation of intrusive igneous rock in this section, the writer suggests that the igneous fragments (and limestone fragments) were derived from conglomerate or breccia in the sandstone-shale sequence; it is significant that the red biotite so abundant in the sandstones is also present in the granodiorite, suggesting that both the sandstones and the granodiorite fragments were derived from the same provenance. Metamorphism in the sandstone-shale sequence is incipient, but the rocks are strongly deformed and extensively invaded by quartz and calcite veins.

This well is interpreted as penetrating Ouachita facies rocks of Mississippian-Pennsylvanian age very close to the Luling overthrust front but north of it in the south part of the frontal zone. The fragments of cataclastically altered granodiorite are similar to those which occur in General Crude No. 1 Rogers Ranch in Bexar County where they occur as the result of tectonic injection in a more highly sheared black slate. Brecciated and partly mylonitized granitic rock also occurs in Humble No. 1 Wilson to the south in Medina County.

X-ray data.—I > Ch; 10/7 ∽ 1; F = 20(?); SR = 1.65. Samples from 2,886 and 3,070 feet do not appear to have been metamorphosed.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; J. B. Souther, Pan American Petroleum Corporation, 1953.

County.—Medina.

Well name.—Roxana Petroleum Company No. 1 Rothe.

Location.—Medina County School Land survey; 1,200 feet FNL, 250 feet FEL; 9 mi. NW of D'Hanis.

Elevation.—1,117 feet. *Total depth.*—ni. *Completed.*—ni.

Top of Paleozoic rocks.—3,000 feet. *Elevation of Paleozoic rocks.*— –1,883 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3020–30, 3130–35, 3300–05, 3400–05, 3527–32 (2).

Description of Paleozoic rocks.—The rocks are dark silty shale, locally containing carbonaceous fragments or small siliceous lenses, locally brecciated, and fine- to medium-grained, mostly angular (some larger grains round), very poorly sorted, dolomitic to calcareous micaceous feldspathic quartz sandstone or arkose containing abundant fragments of bubbly vein quartz, quartz mosaic, chert, and shale; the rocks are veined by quartz and carbonate. In some samples there is incipient reconstitution of the interstitial micaceous-chloritic material.

This sequence is composed of Mississippian-Pennsylvanian beds of Ouachita facies (Stanley-Tesnus); the well penetrated the frontal zone of the Ouachita belt.

X-ray data.—I > Ch > K(?); 10/7 ∼ 1.2; F = 20; SR = 2.3.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Medina.

Well name.—Switzer et al. (also known as O'Dell, Haught and Bond) No. 1 Martin Zerr.

Location.—J. J. Casanova survey; 2,850 feet FNL, 10,500 feet FWL; 5 mi. WNW of Hondo.

Elevation.—927 feet. *Total depth.*—3,635 feet. *Completed.*—1924.

Top of Paleozoic rocks.—3,340 feet. *Elevation of Paleozoic rocks.*— −2,413 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3635–45, 3645–55.

Description of Paleozoic rocks.—Sellards (1933) described the rock encountered in this well as black shale. Thin section study of two samples shows that the sequence contains very fine-grained slightly calcareous (dolomitic?) chloritic micaceous quartz siltstone veined with quartz and carbonate. This well probably penetrated Ouachita facies rocks of Mississippian-Pennsylvanian age (Stanley-Tesnus?) in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1933, p. 190).
Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1956.

County.—Milam.

Well name.—John B. Coffee No. 1 Nelson Davis.

Location.—Miguel Davilla league; 5 mi. W of Sharp.

Elevation.—506 feet, derrick floor. *Total depth.*—3,795 feet. *Completed.*—1955.

Top of metamorphic rocks.—3,745 feet. *Elevation of metamorphic rocks.*— −3,239 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3701–29 (3), 3702, 3722, 3729–59, 3744, 3759–82 (2), 3782–90 (2), 3790–95, 3800.

Description of metamorphic rocks.—Pre-Cretaceous rocks are very highly sheared hematitic chloritic sericite phyllite. Structures are foliation, fracture cleavage, micro-thrust faulting, micro-imbricate structure, and sharp crinkling. Cleavage is nearly vertical in the cores examined. Quartz veins are broken, stretched, and drawn out into augen. Metamorphism is low grade with a very strong shearing element.
This well penetrated the interior zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 $\sim$ 5; SR = 4.8.

References.—Personal communication: B. P. Journeay, 1955.

County.—Milam.

Well name.—D. A. McCrary No. 1 E. M. and J. F. Gibson (was G. L. Reasor No. 1 Gibson).

Location.—J. J. Whiteside survey; 3,450 feet FSWL, 4,900 feet FNWL; 19 mi. N of Cameron.

Elevation.—391 feet, derrick floor; 387 feet, ground. *Total depth.*—6,104 feet. *Completed.*—1955.

Top of metamorphic rocks.—6,100± (?) feet. *Elevation of metamorphic rocks.*— −5,709± (?) feet.

Thin section coverage (depth in feet).—None.

Description of metamorphic rocks.—Reported in "schist" at total depth. From its location, this well penetrated the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1958.

County.—Milam.

Well name.—Rimrock-Tidelands, Incorporated, No. 1 W. F. Crawford.

Location.—Newson Gwatney survey; 517 feet FNEL, 577 feet FSEL; 2½ mi. SE of Clarkson.

Elevation.—351 feet, derrick floor; 342 feet, ground. *Total depth.*—6,995 feet. *Completed.*—1956.

Top of metamorphic rocks.—6,550 feet. *Elevation of metamorphic rocks.*— −6,199 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 6590–00, 6650–60, 6700–10, 6900–10, 7000–03.

Description of metamorphic rocks.—Becwar (1957) reported conglomerate containing phyllite pebbles, 6,490 to 6,550 feet; top of Paleozoic red and green schist, 6,550 to 6,560 feet; top of black slaty shale, phyllite, and schist, 6,590 to 6,600 feet; total depth, 6,995 feet.
The sequence is composed mostly of rutiliferous hematitic graphitic chlorite-sericite and sericite-muscovite phyllite locally invaded by massive quartz veins and masses of secondary carbonate. Many thin sections are nearly opaque due to graphite, hematite, and a dense mat of rutile needles. Structures are foliation, brecciation, contortion, and, locally, fracture cleavage. Metamorphism is low grade with high shearing and metasomatic elements.
The well penetrated the interior zone of the Ouachita belt.

X-ray data.—I > Ch > K; 10/7 ∼ 1; F = 22; SR = 6.4.

References.—Personal communication: H. D. Becwar, The Texas Company, 1957.

County.—Milam.

Well name.—Texas Gulf Sulphur Company No. 1 Baker.

Location.—Jose Leal survey; 43,000± feet S of NE cor., thence 9,100 feet W to location; 3½ mi. W of Milano.

Elevation.—446 feet, kelly bushing; 434 feet, ground. *Total depth.*—12,670 feet. *Completed.*—1955.

Top of metamorphic rocks.—ni. *Elevation of metamorphic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic or metamorphic rocks.—ni.

X-ray data.—None.

References.—Personal communication: J. H. Ogg, Texas Gulf Sulphur Company, 1959.

County.—Navarro.

Well name.—Falcon Drilling Company No. 1 J. C. Keitt.

Location.—Sam Benton survey; subdivision 66; 6 mi. SE of Dawson.

Elevation.—525 feet. *Total depth.*—6,455 feet. *Completed.*—1942.

Top of metamorphic rocks.—6,340 feet. *Elevation of metamorphic rocks.*— -5,815 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 6330–40, 6400–10, 6440–50 (2).

Description of metamorphic rocks.—The sequence in this well is composed of sericitic chloritic metaquartzite and sericite slate. Foliation is well developed and grains are stretched. Metamorphism is low grade with a prominent shearing component.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: B. W. Fox, The Atlantic Refining Company, 1956.

County.—Navarro.

Well name.—H. L. Hunt No. 1 E. E. Hamilton.

Location.—F. R. Kendall survey; 8 mi. W of Corsicana.

Elevation.—485 feet. *Total depth.*—6,674 feet. *Completed.*—1948.

Top of metamorphic rocks.—6,635 feet. *Elevation of metamorphic rocks.*— -6,150 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 6630–40, 6660–70 (2).

Description of metamorphic rocks.—The rocks penetrated in this well are fine-grained dolomitic sericitic metaquartzite and sericite slate. Metamorphism is low grade with a pronounced shearing element; structures are foliation, fracture cleavage, and grain elongation.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—Ch > I; 10/7 ∼ 0.4; F = 20; SR = 24.

References.—Personal communication: B. W. Fox, The Atlantic Refining Company, 1956.

County.—Pecos.

Well name.—Deep Rock Oil Corporation No. 1 Slaughter.

Location.—Section 31, block 129, T&STL survey; 660 feet FSL, 660 feet FEL; 20 mi. SE of Fort Stockton.

Elevation.—3,527 feet. *Total depth.*—10,031 feet. *Completed.*—1952.

Top of Paleozoic rocks.—800 feet. *Elevation of Paleozoic rocks.*— +2,727 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—According to Galley (1957), top of Wolfcamp is at 800 feet and total depth is 10,031 feet in Wolfcamp(?). According to a note in a West Texas Geological Society Guidebook (Adams and Frenzel et. al., 1952), a core from this well from a depth of 2,680 feet shows dips of 65°.

The well penetrated thick lower Permian Wolfcamp clastic rocks north of the Ouachita belt. There is a normal foreland section beneath the Wolfcamp clastics in this general area (p. 136).

X-ray data.—None.

References.—Adams and Frenzel et al. (1952, p. 28).
Personal communication: J. E. Galley, Shell Oil Company, 1957.

County.—Pecos.

Well name.—Phillips Petroleum Company No. 1 Elsinore Cattle Company.

Location.—Section 53, block D, GC&SF survey; 435 feet FSL, 2,095 feet FWL.

Elevation.—4,105 feet, derrick floor. *Total depth.*—12,095 feet. *Completed.*—1946.

Top of Paleozoic rocks.[41] *Elevation of Paleozoic rocks.*— +4,105 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Young (1952) reported the following sequence in this well: spudded in Leonard, probably 200 feet below the top of the Leonard; 0 to 5,530 feet, Leonard dolomite, limestone, and shale; 5,530 to 10,770 feet, Wolfcamp sandstone and shale with limestone at the base; 10,770 to 12,096 feet, Pennsylvanian (Cisco) mostly dark shale with minor limestone and sandstone. A core from 8,110 feet shows that the steep surface dips of the Sierra Madera structure have given way to gentle dips on the order of 12°. More recent studies indicate that top of Wolfcamp may be as high as 1,430 feet and much or all of the sequence identified as Pennsylvanian (Cisco) may be Wolfcamp.

This well is located north of the Ouachita belt.

X-ray data.—None.

References.—Addison Young (1952, pp. 72–73).

County.—Pecos.

Well name.—Transcontinental Oil Company No. 1 Slaughter (Blackwood and Nichols?).

Location.—Section 29, block 129, T&STL survey; 40 mi. SE of Fort Stockton.

Elevation.—3,536(?) feet; 3,544(?) feet. *Total depth.*—4,988 feet. *Completed.*—ni.

Top of Paleozoic rocks.—520 feet. *Elevation of Paleozoic rocks.*— +3016(?), +3024(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Goldstein (1955) reported top of San Andres, 510 feet; top of "sand zone," 1,575 feet; top of black shale, 2,200 feet; total depth 4,988 feet, in foreland(?) facies.

This well is located north of the Ouachita belt and probably penetrated a section of Wolfcamp beds similar to those found in Deep Rock Oil Corporation No. 1 Slaughter.

X-ray data.—None.

References.—Personal communication: J. E. Galley, Shell Oil Company, 1956; August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Real.

Well name.—Stanolind Oil and Gas Company No. 1 Knippa.

Location.—G. H. Boone survey.

Elevation.—1,747 feet. *Total depth.*—8,181 feet. *Completed.*—1953.

Top of Paleozoic rocks.—915 feet. *Elevation of Paleozoic rocks.*— +832 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1240–50, 3080–90, 3270–80, 3700–10, 7440, 7640–50, 7720–30.

Description of Paleozoic rocks.—According to Montgomery (1957), this well topped Paleozoic shales at 935 feet, lower Atokan fusulinids were found from 7,210 to 7,220 feet, and the top of the Ellenburger was encountered at 7,225 feet.

The upper clastic section is composed of fine-grained, angular, slightly feldspathic argillaceous quartz sandstone and dark silty shale, probably Atoka. The lower section is chiefly carbonate and includes calcilutite, fine-grained oolitic pelletiferous limestone, and fine-grained dolomite.

This well penetrated foreland facies rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957; J. B. Souther, Pan American Petroleum Corporation, 1956.

[41] Well was spudded in Permian (Leonard) rocks on the Sierra Madera structure.

County.—Red River.

Well name.—Bentley, Shepherd, and Stevens No. 1 Southern Pine Lumber Company.

Location.—George W. Parks (West) survey; 10,250 feet FSL, 400 feet FWL; 17 mi. N of Clarksville.

Elevation.—414 feet. *Total depth.*—1,868 feet. *Completed.*—1939.

Top of metamorphic rocks.—1,810 feet. *Elevation of metamorphic rocks.*— –1,396 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1841, 1843–45, 1845–47, 1860–68.

Description of metamorphic rocks.—The sequence encountered in this well is composed of sericite phyllite and hornblende metaquartzite; fracture cleavage is developed in the phyllite. Metamorphism is low grade with a strong shearing element.

This well penetrated metamorphosed rocks in the southwestern subsurface extension of the Broken Bow—Benton uplift of the Ouachita Mountains. Probably the rocks are lower Paleozoic Ouachita facies.

X-ray data.—None.

References.—Personal communication: B. W. Fox, The Atlantic Refining Company, 1956.

County.—Red River.

Well name.—S. M. Brasfield No. 1 Eichenberg and Miller.

Location.—George S. Park survey; 330 feet FEL, 2,850 feet FSL; 15 mi. NE of Clarksville.

Elevation.—415 feet, derrick floor. *Total depth.*—1,808 feet. *Completed.*—1956.

Top of metamorphic rocks.—1,800 feet. *Elevation of metamorphic rocks.*— –1,385 feet.

Thin section coverage (depth in feet).—None.

Description of metamorphic rocks.—Love, Kirkland, and Richey (1957) reported top of "Paleozoic schist" at 1,800 feet.

This well encountered metamorphosed rocks in the southwestern subsurface extension of the Broken Bow—Benton uplift of the Ouachita Mountains. The rocks are probably lower Paleozoic Ouachita facies.

X-ray data.—None.

References.—Love, Kirkland, and Richey (1957, p. 1179).
Personal communication: B. W. Fox, The Atlantic Refining Company, 1956.

County.—Red River.

Well name.—Byars No. 1 Chapman.

Location.—H. B. Shaw survey; 26 mi. NE of Clarksville.

Elevation.—346 feet. *Total depth.*—3,323 feet. *Completed.*—1954.

Top of Paleozoic rocks.—3,162 feet. *Elevation of Paleozoic rocks.*— –2,816 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3000–10, 3250–60, 3270–80.

Description of Paleozoic rocks.—The Paleozoic rocks encountered in this well are fine-grained, angular to subround, poorly sorted, calcareous and micaceous quartz sandstone containing varied amounts of feldspar. There is no metamorphism. The lithology is more typically Atoka than Stanley, but on the basis of well location the section is identified as Stanley(?).

This well penetrated rocks of the Ouachita belt southeast of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Personal communication: B. W. Fox, The Atlantic Refining Company, 1956.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Red River.

Well name.—Concord Oil Company (Pearsons et al.) No. 1 Dillahunty.

Location.—I. Moore survey; 200 feet FNL, 200 feet FWL; 3 mi. FW County line; 6 mi. S of Red River.

Elevation.—482 feet. *Total depth.*—2,545 feet. *Completed.*—1933.

Top of metamorphic rocks.—2,137(?) feet. *Elevation of metamorphic rocks.*— –1,655(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2137 (2).

Description of metamorphic rocks.—Sellards (1933, p. 190) reported schistose sandy shale from depths of 2,137 and 2,500 feet. Barnes (*in* Sellards, 1933, p. 135) noted that the core shows almost horizontal crinkly cleavage and that the rock is composed mostly of chlorite with lesser amounts of sericite and quartz; he remarked that the metamorphism is "rather advanced."

Thin section examination shows that the rock is a chlorite slate or phyllite; metamorphism is weak. Foliation was the only structure observed.

This well penetrated metamorphosed rocks in the southwestern subsurface extension of the Broken Bow—Benton uplift of the Ouachita Mountains. Probably the rocks are lower Paleozoic Ouachita facies.

X-ray data.—None.

References.—Sellards (1933, pp. 135, 190).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Red River.

Well name.—D. J. Flesh et al. No. 1 K. M. Bailey.

Location.—John Robbins survey; 1 mi. W of Bagwell.

Elevation.—446 feet. *Total depth.*—3,377 feet. Completed.—1939.

Top of Paleozoic or metamorphic rocks.—3,375 feet. *Elevation of Paleozoic or metamorphic rocks.*—
−2,929 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 3355–65.

Description of Paleozoic or metamorphic rocks.—A note in the Bureau of Economic Geology files describes fragments from the 3,360-foot interval as schistose shale. The single sample examined for this study is rutiliferous argillaceous siliceous rock, possibly a chert. This well probably penetrated metamorphosed lower Paleozoic rocks of Ouachita facies in the southwestern subsurface extension of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Bureau of Economic Geology files.
Personal communication: B. W. Fox, The Atlantic Refining Company, 1956.

County.—Red River.

Well name.—Johnston Petroleum Syndicate No. 1 Lady Alice (Antone and Martin).

Location.—Robert T. Gamble survey; 1,067 varas FSL, 215.1 varas FEL; at Silver City, 18 mi. N of Clarksville.

Elevation.—397 feet. *Total depth.*—4,470 feet. *Completed.*—Before 1923.

Top of metamorphic rocks.—1,763 feet. *Elevation of metamorphic rocks.*— −1,366 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1977–2080 (2).

Description of metamorphic rocks.—Sample descriptions in files of the Bureau of Economic Geology report phyllite, quartzite, sandy marble, graphite schist, vein quartz, and calcite from 1,763 to 2,522 feet, and mostly graphite schist and vein quartz and calcite from 2,522 to 4,491 feet. Sellards, in reexamination of the cuttings, described the rocks below 1,763 feet as mostly hard black shale or phyllite, locally graphitic, with vein quartz and calcite. A note (author unknown) suggests samples from 4,000 to 4,491 feet may be metamorphosed Stanley shale.

Miser and Sellards (1931, p. 811) stated that this well passed from Lower Cretaceous beds into Paleozoic rocks at a depth of 1,673 feet (note discrepancy above) and remained in Paleozoic rocks to total depth of 4,520 feet (note discrepancy above). They reported that the cuttings consist of shale with some interbedded limestone and sandstone. The shale is bluish black to black, shows shiny surfaces, and has been metamorphosed, some having been changed to slate or phyllite. Much of the shale is papery and shows crumpling; the sandstone is gray and locally quartzitic; the limstone is gray and sandy; white quartz and calcite are plentiful in the samples and probably occur as veins. T. L. Bailey described a sample from this well from 1,763 to 1,767 feet as a shiny slate-gray phyllite composed principally of quartz and biotite. Miser and Sellards (1931, p. 812) remarked that the cuttings from the No. 1 Lady Alice are comparable in lithology to the Womble shale, Blakely sandstone, Mazarn shale, Crystal Mountain sandstone, and Collier shale, and they concluded that the sequence in this well is Cambrian or Ordovician in age.

Thin section examination shows that the rocks are chlorite-sericite slate, locally phyllitic, chloritic, and sericitic metachert or very fine-grained metaquartzite, and fine-grained quartzose dolomitic calcite marble, locally graphitic. Metamorphism is weak to low grade with a pronounced shearing element; foliation in marbles is expressed in stretched grains and development of parallel shear planes. The sequence is probably composed of metamorphosed lower Paleozoic Ouachita facies rocks similar to those to the northeast exposed in the Broken Bow—Benton uplift of the Ouachita Mountains; the marbles are similar to those penetrated in Val Verde County.

This well penetrated metamorphic rocks in the subsurface southwestern extension of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Miser and Sellards (1931, pp. 811–812); Sellards (1933, p. 190).
Bureau of Economic Geology files.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Red River.

Well name.—Magnolia Petroleum Company No. 1 Henry.

Location.—MBP&P survey; 640 feet FWL, 700 feet FNL; 4½ mi. NE of Deport.

Elevation.—472 feet. *Total depth.*—4,788 feet. *Completed.*—1941.

Top of Paleozoic and metamorphic rocks.—4,490 feet. *Elevation of Paleozoic and metamorphic rocks.*— -4,018 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 4225, 4285, 4335, 4565, 4585, 4615, 4760, 4785. SHELL OIL COMPANY: 4744–47.

Description of Paleozoic and metamorphic rocks.—Goldstein (1955) reported base of Cretaceous and probable top of Paleozoic, 4,490 feet; total depth 4,788 feet, in Paleozoic rocks. He noted that at 4,490 feet the drill penetrated red indurated shales, argillites, and red quartzitic sandstone cut by quartz veins; red and gray quartzites were encountered to 4,770 feet; at 4,780 to 4,790 feet a single sample is contorted quartz-mica phyllite.

Thin section studies of samples from 4,560±, 4,565, 4,585, and 4,615 feet show that the rocks are red, fine-grained, angular, mostly poorly sorted, hematitic quartz sandstones and dark red hematitic sandy and silty micaceous metashale; quartz veins are common. Metamorphism in this upper section ranges from none to incipient. The lower sequence is composed of metamorphosed rocks: 4,744 to 4,747 feet, hematitic chlorite-sericite phyllite; 4,760 feet, fine-grained, angular, poorly sorted, feldspathic high-rank metasandstone; 4,785 feet, hematitic sericite phyllite. The phyllites are foliated rocks showing microfolding and abundant quartz veins. Metamorphism is weak to low grade with a prominent shearing component.

Goldstein (1955) suggested that the upper red-bed sequence is probably deeply weathered Paleozoic sediments of Ouachita facies but pointed out that it could be a post-Pennsylvanian unit such as Eagle Mills. In the writer's opinion the presence of abundant quartz veins and the nature of the sandstones indicate that the red-bed sequence is of Ouachita facies. The change from unmetamorphosed rocks in the upper part of the section to metamorphic rocks in the lower part is very likely due to faulting or folding.

This well penetrated Ouachita facies rocks (lower Paleozoic?) in the subsurface southwestern extension of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Red River.

Well name.—Texas Trading Company No. 1 Southern Pine Lumber Company.

Location.—D. D. Bruton survey; 11 mi. N of Detroit.

Elevation.—407 feet. *Total depth.*—2,383 feet. *Completed.*—ni.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2370–80, 2382–83.

Description of Paleozoic rocks.—Bureau of Economic Geology files report quartzite and mica at 2,382 to 2,383 feet. Petrographic study of two samples available shows the rock is fine-grained, angular to subround, poorly sorted, slightly argillaceous chloritic micaceous feldspathic quartz low-rank metasandstone containing layers and streaks of dark metashale and extensively veined with quartz; the rock shows partial reconstitution of intergranular material to mica-chlorite and, locally, shearing. One fragment contains grains of sheared chert and vein quartz. The sequence is identified as very weakly metamorphosed Stanley on the southeast side of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Red River.

Well name.—The Texas Company No. 1 H. O. Solomon.

Location.—W. E. Edwards survey; 3,150 feet FNL of Edwards survey, 660 feet FWL of M. Blankston survey; 10 mi. SW of Annona.

Elevation.—347 feet. *Total depth.*—6,152 feet. *Completed.*—1944.

Top of Paleozoic rocks.—6,045 feet. *Elevation of Paleozoic rocks.*— -5,698 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 5920, 6000, 6060, 6080, 6110, 6125.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Paleozoic of Ouachita facies at 6,045 feet, total depth, 6,150 feet.

The rocks from 6,060 to 6,110 feet are fine-grained, angular, poorly sorted, tightly packed, hematitic to quartzitic feldspathic micaceous quartz sandstone containing up to 5 percent metamorphic rock fragments; they show incipient to very weak metamorphism. At 6,125 feet the sample is sericite slate with well-developed foliation.

This well penetrated Ouachita facies rocks (possibly Stanley overlying older Ouachita rocks) southeast of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Red River.

Well name.—Welch Petroleum Company No. 1 R. Williams.

Location.—Lanson Moore survey; 2,871 feet F most E'ly EL, 4,089 feet F most E'ly SL; 6 mi. N of Manchester.

Elevation.—393 feet, derrick floor. *Total depth.*—1,168 feet. *Completed.*—1956.

Top of Paleozoic or metamorphic rocks.—1,124 feet. *Elevation of Paleozoic or metamorphic rocks.*— -731 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic or metamorphic rocks.—ni.

X-ray data.—None.

References.—Love, Kirkland, and Richey (1957, p. 1179).
Personal communication: B. W. Fox, The Atlantic Refining Company, 1957.

County.—Red River.

Well name.—Joe White et al. No. 1 Kurth Lumber Company.

Location.—Elizabeth Smith survey; 3,260 feet S and 600 feet W of NE cor.; 12 mi. N of Clarksville.

Elevation.—410 feet. *Total depth.*—2,139 feet. *Completed.*—1940.

Top of Paleozoic rocks.—2,133 feet. *Elevation of Paleozoic rocks.*— -1,723 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1965–2090, 2090–2135.

Description of Paleozoic rocks.—The rock is dark microgranular to cryptocrystalline chert—probably Bigfork. This well is located on the southeast margin of the southwestern subsurface extension of the Broken Bow—Benton uplift of the Ouachita Mountains.

X-ray data.—None.

References.—Personal communication: B. W. Fox, The Atlantic Refining Company, 1956.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Terrell.

Well name.—Big Bend No. 1 Bassett.

Location.—Section 156, block D, MK&TE survey; 1,320 feet FNL, 1,320 feet FEL; 3½ mi. S, 15 mi. W of NW cor. of Val Verde County.

Elevation.—2,396 feet. *Total depth.*—2,669 feet. *Completed.*—1931.

Top of Paleozoic rocks.—1,130 feet. *Elevation of Paleozoic rocks.*— +1,266 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Kleihege (1948) noted that this well penetrated a pre-Cretaceous section composed of about 1,300 feet of very fine-textured clayey green shale with subordinate thin beds of brown shale. Woods (1955) remarked that samples from 2,370 to 2,610 feet are all slightly metamorphosed.

The well appears to be close to the Ouachita front (Pl. 2); most probably the sequence is composed of Pennsylvanian or Permian foreland basin rocks.

X-ray data.—None.

References.—Kleihege (1948, p. 22).
Personal communication: R. D. Woods, Humble Oil & Refining Company, 1955.

County.—Terrell.

Well name.—BLT Company No. 2 M. C. Goldwire.

Location.—Section 95, block 1, TCRR survey; 7 mi. N of Sanderson.

Elevation.—3,529 feet. *Total depth.*—3,036 feet. *Completed.*—1952.

Top of Paleozoic rocks.—1,000±(?) feet. *Elevation of Paleozoic rocks.*— +2,529±(?) feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1950 (2).

Description of Paleozoic rocks.—The two thin sections examined are angular to subangular, fairly well-sorted, micaceous chloritic feldspathic quartz siltstone, locally argillaceous; the rock contains both plagioclase and potassium feldspar.

No reliable identification can be made from these samples; on the basis of location, this well probably penetrated Tesnus beds in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1958.

County.—Terrell.

Well name.—Briggs No. 1 Kerr.

Location.—Section 18, block D5, HE&WT survey; 1,800 feet FWL, 790 feet FNL.

Elevation.—2,150 feet. *Total depth.*—3,000±(?) feet. *Completed.*—1944.

Top of Paleozoic rocks.—1,335(?) feet. *Elevation of Paleozoic rocks.*— +815(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic or metamorphic rocks.—Information gathered on this well is conflicting. According to Kleihege (1949), the well penetrated well-cemented dolomitic fine-grained buff to tan sandstone containing traces of gypsum (depth 2,735 to 2,868 feet) and moderately crystalline tan dolomite (2,890 to 2,993 feet); he noted that the dolomite is similar to the Ellenburger dolomite encountered in Shell No. 1 Honeycutt in Edwards County and suggested that inasmuch as the well is located "south of the belt of metamorphosed rocks," it may have penetrated an overthrust. Galley (1956) said that according to available records, total depth of this well is 1,265 feet, still in Trinity beds. No samples of the pre-Cretaceous section were located.

From the location of this well (Pl. 2), the pre-Cretaceous rocks should be very weakly metamorphosed Ouachita (Marathon) facies rocks—Tesnus and/or pre-Tesnus. Possibly the dolomite observed by Kleihege is Cretaceous dolomite (see p. 285), or possibly there was some confusion in the samples. If Ellenburger (or lower Paleozoic foreland facies carbonate rock) was penetrated in this well, an overthrust and possibly a fenster are indicated.

X-ray data.—None.

References.—Kleihege (1948, p. 50).
Personal communication: J. E. Galley, Shell Oil Company, 1956.

County.—Terrell.

Well name.—Downie Test Well.

Location.—Section 21, block MM; 10 mi. N of Sanderson.

Elevation.—2,600 feet (from topographic map). *Total depth.*—ni. *Completed.*—ni.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in the files of the Bureau of Economic Geology report gray sandstone and black shale at 720 feet and indicate that the sequence may be Tesnus. The location of the well is compatible with the identification of Tesnus.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Terrell.

Well name.—Downie Water Well.

Location.—Section 11, block R4, GC&SF survey.

Elevation.—ni. *Total depth.*—ni. *Completed.*—ni.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in the files of the Bureau of Economic Geology report black shale from 500 to 1,325 feet. This well probably penetrated Ouachita (Marathon) facies rocks, possibly Tesnus beds.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Terrell.

Well name.—Dryden Oil Corporation No. 1 Bassett Trust Company.

Location.—Section 68, block A-2, GH&SA survey; 3½ mi. SE of Dryden.

Elevation.—2,197 feet. *Total depth.*—1,694 feet. *Completed.*—1956.

Top of Paleozoic rocks.—1,550± feet. *Elevation of Paleozoic rocks.*— +647± feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1630–90 (3).

Description of Paleozoic rocks.—The single sample thin-sectioned for this study is dark brecciated and deformed metashale or clay-slate, dark slightly calcareous microgranular to microspherulitic chert containing dark organic material, and dark slightly silty argillaceous and micaceous siliceous dolomite containing a few spicules; the rocks are veined with quartz and bituminous material.

The well penetrated incipiently to very weakly metamorphosed pre-Tesnus Ouachita facies rocks in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—None.

County.—Terrell.

Well name.—R. E. Freeman No. 1 Barksdale.

Location.—Section 50, block A-2, GH&SA survey; 600 feet FNL, 1,980 feet FEL; 7 mi. E of Dryden.

Elevation.—2,075 feet. *Total depth.*—8,747 feet. *Completed.*—1956.

Top of Paleozoic rocks.—1,565 feet. *Elevation of Paleozoic rocks.*— +510 feet.

Thin section coverage (depth in feet). SHELL OIL COMPANY: 3380–86 (5), 5576–86 (2), 5670–80, 5715–29, 5729–42, 5775–87 (2), 5787–96 (2), 5796–5809, 5809–20 (2), 5820–32 (2), 5832–45 (2), 5845–54 (2), 5880–92, 5892–5900 (2), 5914–25, 5955–63, 5990–03 (3), 6003–18, 6027–44 (2), 6044–58 (2), 6072–85 (2), 6098–6110 (2), 6230–44, 6273–81, 7985–00, 8540–60 (2), 8560–70, 8560–86, 8580–90, (2), 8590–00, 8600–20 (2), 8620–40 (2), 8640–60, 8660–70.

Description of Paleozoic rocks.—Kleihege (1949) reported the rocks beneath the Cretaceous as very fine-textured glossy variegated slaty shale. Olson (1958) remarked that the sample log on this well shows a predominantly shale section.

Petrographic study shows that the sequence is composed mainly of: (1) black finely dolomitic and calcareous shale, commonly siliceous, and containing abundant black opaque material that is probably a bitumen; in some intervals the rocks are metashale and clay-slate with incipient foliation and, locally, fracture cleavage; and (2) dark fine-grained dolomitic spiculitic limestone, commonly silty, pyritic, siliceous, and bituminous, locally containing shell fragments, pelmatozoan debris, and authigenic feldspar; in some intervals the limestone is strongly sheared—calcite is deformed, stretched, and extensively twinned. Minor rock types in the sequence include fine-grained dolomite and dark dolomitic argillaceous spiculitic chert. The spicules in the limestones and cherts are, with rare exceptions, calcite. The rocks are cut by pre-metamorphism veins of calcite, dolomite, and quartz which also show evidence of strong shear—calcite is deformed and very extensively twinned; commonly it forms a mosaic with strained quartz. Metamorphism is difficult to assess because of the obscuring effect of the abundant bituminous material in the shales. It appears to be much more intense in some intervals than in others (zones of shearing); probably the highest grade of metamorphism attained is very weak to weak.

The well penetrated incipiently to very weakly metamorphosed pre-Tesnus rocks (probably Marathon limestone) in the frontal zone of the Ouachita structural belt. In outcrop, the Marathon limestone shows considerable variation in the carbonate/clastic ratio; in the Dagger Flat area, for example, it is mostly shale.

X-ray data.—None.

References.—Kleihege (1948, p. 26).

Personal communication: J. P. Olson, Shell Oil Company, 1958.

County.—Terrell.

Well name.—Humble Oil & Refining Company No. 1 N. D. Blackstone.

Location.—Section 58, block B-2, CCSD&RGNG survey.

Elevation.—2,671 feet. *Total depth.*—12,303 feet. *Completed.*—1953.

Top of Paleozoic rocks.—840± feet. *Elevation of Paleozoic rocks.*— +1,831± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Hull (1957a) reported top of Wolfcamp, 5,365 feet; base of Wolfcamp and top of Strawn, 11,220 feet; Canyon and Cisco sections are missing. The Wolfcamp sequence is dark shale, fine-grained quartzitic sandstone, and fragmental limestone.
This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Hull (1957a, p. 88).

County.—Terrell.

Well name.—Humble Oil & Refining Company No. 1 J. C. Mitchell.

Location.—Section 24, block 128, T&STL survey; 1,700 feet FNL, 2,080 feet FEL; 30 mi. N of Sanderson.

Elevation.—3,010 feet. *Total depth.*—12,074 feet. *Completed.*—1949.

Top of Paleozoic rocks.—600 feet. *Elevation of Paleozoic rocks.*— +2,410 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1460–70 (2), 1720–30 (3), 3130–40 (2), 3230–40 (2), 3610–20 (3), 4850–60, 5900–10 (3), 5930–40 (2), 6390–00 (3).

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Leonard, 600 feet; base of Leonard fusulines and top of Wolfcamp fusulines, 3,710 feet; base of Wolfcamp fusulines, 5,930 feet: total depth 12,074 feet, in Pennsylvanian. Galley (1957) reported top of Leonard, 660 feet; top of Wolfcamp, 3,540 feet; total depth in Wolfcamp(?), 12,074 feet.
This well penetrated foreland basin rocks north of the Ouachita structural belt.

X-ray data.—$I > ML > Ch > K$; $10/7 \sim 2$; $F = 20$: $SR = 1.3$.

References.—Personal communication: J. E. Galley, Shell Oil Company, 1957; August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Terrell.

Well name.—Humble Oil & Refining Company No. 1 University.

Location.—Section 15, block 34, University survey; 490 feet FNL, 2,790 feet FEL.

Elevation.—2,284(?), 2,366(?) feet. *Total depth.*—4,470 feet. *Completed.*—1928.

Top of Paleozoic rocks.—615 feet. *Elevation of Paleozoic rocks.*— +1669(?), 1751(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—ni.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Terrell.

Well name.—Keck-Pecos Trust (Trans-Pecos Development Company) No. 1 Hamilton.

Location.—Section 6, Cedar Springs block D-7, MK&TE survey; 6 mi. N of Rio Grande, 2 mi. W of County line.

Elevation.—1,736 feet. *Total depth.*—3,165 feet. *Completed.*—1928; 1932.

Top of Paleozoic rocks.—2,230 feet. *Elevation of Paleozoic rocks.*— —494 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in Bureau of Economic Geology files report hard black shale, not appreciably altered, in the interval 2,780 to 2,810 feet. Kleihege (1949) described the sequence as follows: base of Trinity, 2,230 feet; 2,280 to 2,450 feet, black dense fine-textured and slightly micaceous shale with a few thin beds of gray very fine-grained well-cemented sandstone; 2,450 to 2,583 feet, predominantly sandstone; 2,715 to 2,830 feet, variegated blocky shale overlying interbedded gray sandstone and black finely arenaceous slate, in turn overlying 50 feet of glossy black slate veined by quartz and calcite; 2,860 to 2,920 feet, black arenaceous shale overlying slaty micaceous fine-grained sandstone; 2,965 feet, variegated blocky arenaceous shale; below 2,965 feet, finely arenaceous black micaceous shale.

These rocks are probably very weakly metamorphosed Tesnus. This well appears to have penetrated the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Kleihege (1948, pp. 39–40).
Bureau of Economic Geology files.

County.—Terrell.

Well name.—Magnolia Petroleum Company and Western Natural Gas No. 1 Brown and Bassett.

Location.—Section 218, block Y, TCRR survey; 25 mi. S of Sheffield.

Elevation.—2,448 feet. *Total depth.*—15,556 feet. *Completed.*—1957.

Top of Paleozoic rocks.—875 feet. *Elevation of Paleozoic rocks.*— +1,573 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 15,440–45 (2), 15,460–65, 15,480–85, 15,500–05, 15,520–25, 15,540–45, 15,550–55.

Description of Paleozoic rocks.—Vinson (1957) reported top of Strawn limestone, 11,435 feet; top of Mississippian limestone, 11,540 feet; top of Woodford, 11,584 feet; top of Devonian, 11,920 feet; top of Simpson, 12,448 feet; top of Ellenburger, 13,755 feet; top of Wilberns, 15,365 feet; top of Precambrian, 15,442 feet; total depth 15,556 feet, in Precambrian.

This well penetrated a very thick foreland basin section north of the Ouachita belt. It is one of the few wells which has encountered Precambrian rocks in this general area.

The Precambrian basement rocks are (1) metavolcanic rock composed of magnetite, calcite, and oligoclase with traces of biotite and hornblende and showing a relict microlitic fabric; (2) leucomicrogranite; and (3) magnetite-quartz-biotite-hornblende-oligoclase gneiss. The rocks are cut by quartz and hornblende veinlets. Metamorphism is medium grade regional metamorphism; structures are imperfect foliation (gneiss) and fracturing (microgranite). These rocks may be part of the Van Horn orogenic belt (Flawn, 1956).

X-ray data.—None.

References.—Flawn (1956, pp. 32–36).
Personal communicaion: M. C. Vinson, Magnolia Petroleum Company, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Terrell.

Well name.—Milham Oil Corporation No. 1 Bassett.

Location.—Section 76, block Y, W. H. Robinson survey; 2,640 feet FEL, 150 feet FNL; 6 mi. W and 7½ mi. S of NW cor. of Val Verde County (also reported as section 99).

Elevation.—2,215 feet. *Total depth.*—5,475 feet. *Completed.*—1929.

Top of Paleozoic rocks.—1,215 feet. *Elevation of Paleozoic rocks.*— +1,000 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1275–79, 1304–10, 1498–1505, 1512–17, 1600–08, 3565–95.

Description of Paleozoic rocks.—Lewis (1941) reported about 2,300 feet of dark calcareous shale overlying several hundred feet of dark sandy shale with graptolites and ostracods resembling the fauna of the Woods Hollow formation throughout several hundred feet of section just below the Cretaceous; the lower sequence does not resemble the strata below the Woods Hollow in the Marathon Basin and may be Permian in age. The apparent thickness of the Woods Hollow-type beds suggests steep dips. Goldstein (1955) reported base of Cretaceous and top of Woods Hollow(?), 1,215 feet; top of Pennsylvanian(?), 3,565 feet; total depth 5,300 feet, in Pennsylvanian(?); he suggests that Woods Hollow(?) of Marathon facies is thrust over foreland facies Pennsylvanian beds. Kleihege (1949) noted the presence of 2,300 feet of fine-textured green shale overlying 1,700 feet of black fine-textured arenaceous shale; he stated that there is a distinct lithologic break between the two units and remarked that the lower black shale sequence is similar to the Pennsylvanian black shales found in wells to the east.

Skinner (1958), from a study of the ostracods, noted that the well penetrated alternating Mississippian and Pennsylvanian (Morrow) beds below the Cretaceous; he cast some doubt on previous graptolite work. The repetition of Mississippian-Pennsylvanian sequence indicates complex structure. Olson (1958) remarked that on basis of ostracod fragments this well penetrated Silurian thrust over Pennsylvanian(?).

Sample coverage available shows that the upper unit is composed of dark commonly dolomitic or sideritic silty shale, locally hematitic, pyritic, and carbonaceous. No sample coverage is available on the deeper parts of this well.

This well is close to the northern boundary of the Ouachita belt and may have penetrated lower Paleozoic Marathon facies rocks thrust over Pennsylvanian beds or Mississippian-Pennsylvanian beds in a disturbed zone along the Ouachita front.

X-ray data.—Shallow samples: ML > I > K > Ch; 10/7 ~ 0.5; F = 20; SR = 1.0. Woods Hollow shale from Marathon outcrops also contains abundant mixed-layer clay.

References.—Kleihege (1948, p. 22); Lewis (1941, pp. 78–79).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; J. P. Olson, Shell Oil Company, 1958; John Skinner, Humble Oil & Refining Company, 1958; R. D. Woods, Humble Oil & Refining Company, 1955.
Incomplete samples are in Bureau of Economic Geology Well Sample Library.

County.—Terrell.

Well name.—Perkins and Lierney No. 1 McCue.

Location.—Section 3, block 152, GC&SF survey; 1½ mi. N of Sanderson.

Elevation.—2,908 feet. *Total depth.*—1,498 feet. *Completed.*—1947.

Top of Paleozoic rocks.—775 feet. *Elevation of Paleozoic rocks.*— +2,133 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—From its location, this well probably penetrated rocks of Ouachita (Marathon) facies in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1958.

County.—Terrell.

Well name.—Pittsburgh Western Company No. 1 Downie.

Location.—Section 36, block R2, GC&SF survey.

Elevation.—3,115 feet. *Total depth.*—1,250 feet. *Completed.*—ni.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—From its location, this well probably penetrated very weakly metamorphosed rocks of Ouachita (Marathon) facies in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Terrell.

Well name.—Sides No. 1 Rose.

Location.—Section 15, block 148, T&STL survey; 440 feet FSL, 440 feet FWL.

Elevation.—2,618 feet. *Total depth.*—1,320 feet. *Completed.*—1944.

Top of Paleozoic rocks.—860± feet. *Elevation of Paleozoic rocks.*— +1,758+(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—ni.

X-ray data.—None.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1959.

County.—Terrell.

Well name.—Skelly Oil Company No. 1 Roberts.

Location.—Section 190, block D, MKT survey; 660 feet FNL, 660 FEL; 45 mi. NE of Sanderson.

Elevation.—2,774 feet, derrick floor. *Total depth.*—3,940 feet. *Completed.*—1942.

Top of Paleozoic rocks.—1,180 feet. *Elevation of Paleozoic rocks.*— +1,594 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1180–90 (4), 1210–20, 1240–50, 1430–40, 1670–80.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Pennsylvanian(?) of foreland facies(?) at 1,180 feet; total depth 3,940 feet, in Pennsylvanian.

The rocks are mostly dark-colored silty carbonaceous shales veined with calcite and, locally, red hematitic shales. There is no evidence of metamorphism. This well appears to be very close to the northern limit of the Ouachita belt; the rocks are probably foreland facies.

X-ray data.—I > ML > K > Ch; 10/7 ~ 1.4; SR = 1.6. Ch becomes more abundant than K with depth.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; R. D. Woods, Humble Oil & Refining Company, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Terrell.

Well name.—Southwest Texas Oil and Gas Association No. 1 A. T. Folsom.

Location.—Section 148, block D7, ELRR survey; 8 mi. S of Watkins.

Elevation.—1,703(?), 1,850(?) feet. *Total depth.*—3,580(?), 3,650(?) feet. *Completed.*—1918(?); 1921(?).

Top of Paleozoic rocks.—1,970(?) feet. *Elevation of Paleozoic rocks.*— -267(?), -120(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2297, 2654, 2752, 2795–2805, 2800–10 (4), 2819–61, 2880–90, 2948–52, 2952–3001 (2), 3001–27, 3027–70, 3070–80, 3080–3100 (2), 3100–08, 3108–18, 3118–53, 3153–88 (2), 3188–22 (3), 3222–26, 3250, 3266–70 (2), 3270–90, 3290–3300, 3300–3420, 3457–65, 3580 (2).

Description of Paleozoic rocks.—Sellards (1933) placed approximate top of Paleozoic at 1,970 feet; elevation from topographic map is 1,850 feet; total depth is 3,580 feet; he described the rock as schistose shale. Goldstein (1955) referred to Sellards (1933) but reported an elevation of 1,703 feet; he identified the section as Marathon facies showing incipient to very weak metamorphism. R. D. Woods (1955) remarked that there are three elevations on record for this well—1,703, 1,850, and 2,600 feet—and that 1,703 feet appears to be correct from the topographic map. Kleihege (1949) noted a total depth of 3,650 feet and described the sequence as follows: 2,115 to 2,690 feet, gray fine-textured sandstones and black fine-textured slates, some of which are phyllitic; from 2,215 to 2,905 feet there is a general decrease in metamorphism; 2,740 to 3,065 feet, dense black fine-textured shale decreasing in metamorphism from slate to shale; 3,070 to 3,185 feet, black dense cherty phyllitic slate permeated by quartz veins; 3,190 to 3,260 feet, black fine-textured slate; 3,315 to 3,580 feet, olive-green glossy phyllitic slate which is a fine-textured matrix of chlorite flakes having cataclastic structure. Kleihege remarked that the alternation of differing grades of metamorphism indicates that folded or thrust-faulted rocks have been penetrated.

Thin section study shows that the sequence is composed of dark carbonaceous and micaceous shale, locally silty and sandy, dark siliceous shale and argillaceous chert, fine-grained, angular, poorly sorted, tightly packed, chloritic micaceous argillaceous carbonaceous quartz sandstone and metasandstone, and dark carbonaceous to graphitic sericitic chloritic metashale, clay-slate, and slate, locally sandy, pyritic, and siliceous. Vein material including quartz, dolomite, and chlorite is common in intervals showing higher metamorphism. Metamorphism ranges from incipient to very weak to weak with incipient foliation developed in the higher grade rocks. Clay-slate and slate are closely associated with shale and metashale.

The observed changes in metamorphic grade in this well may be explained by (1) folding and faulting (as noted by Kleihege) with metamorphic grade being more advanced along axial planes and faults and/or (2) variations in susceptibility to metamorphism of different rock types in the sequence (p. 15).

The sequence penetrated in this well resembles very weakly metamorphosed Tesnus and is tentatively identified as Tesnus. The well appears to have encountered Ouachita (Marathon) facies rocks in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Kleihege (1948, p. 38); Sellards (1933, p. 190).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; R. D. Woods, Humble Oil & Refining Company, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Terrell.

Well name.—Sun Oil Company No. 1 Scott.

Location.—Section 12, block R, TCRR survey; center of NE/4.

Elevation.—2,442(?) feet (from topographic map.) *Total depth.*—4,020 feet. *Completed.*—1927.

Top of Paleozoic rocks.—900(?) feet. *Elevation of Paleozoic rocks.*— +1,542(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Cannon and Cannon (1932) stated that the well entered typical upper Cisco at 3,250 feet.

This well penetrated upper Paleozoic foreland rocks north of the Ouachita belt.

X-ray data.—None.

References.—Cannon and Cannon (1932).

County.—Terrell.

Well name.—Irvin Svoboda No. 1 J. L. Bassett.

Location.—Section 1, block 149, T&STL survey.

Elevation.—2,467 feet. *Total depth.*—2,180 feet. *Completed.*—1948.

Top of Paleozoic rocks.—1,100 to 1,200 feet (estimated). *Elevation of Paleozoic rocks.*— +1,267 to +1,367 feet (estimated).

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—ni.

X-ray data.—None.

References.—Personal communication: R. D. Woods, Humble Oil & Refining Company, 1956.

County.—Terrell.

Well name.—Texas Consolidated Oil Company No. 1 Holmes.

Location.—Section 14, block A2, GH&SA survey; 467 feet FNL, 467 feet FEL; 5½ mi. NW of Dryden.

Elevation.—2,760 feet. *Total depth.*—2,015 feet. *Completed.*—1941.

Top of Paleozoic rocks.—1,420(?) feet. *Elevation of Paleozoic rocks.*— +1,340(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1420–30, 1500–10, 1540–44, 1545–50, 1639–45 (2).

Description of Paleozoic rocks.—According to Kleihege (1949), the interval 1,420 to 1,700 feet is characterized by a gradual increase in grade of metamorphism from black shale at the top to slate at the bottom; the shales are arenaceous at the top and beds of fine-grained gray well-cemented sandstone are present. There are thin beds of gray quartzite at 1,560 and 1,615 feet. From 1,630 to 1,700 feet the rock is black fine-textured slate. Between 1,800 and 1,870 feet, slate grades to black shale and from 1,875 to 1,935 feet there is another alternation to slate. Kleihege noted that the change in metamorphic grade may indicate folding or thrust-faulting. Goldstein (1959) studied samples from 1,420 to 1,936 feet and considered the sequence to be weakly metamorphosed Tesnus.

Limited thin section coverage shows a sequence of dark sandy and silty shale and metashale, fine-grained, angular, poorly sorted, tightly packed, feldspathic quartz sandstone, locally micaceous, and dark micaceous chloritic clay-slate; the rocks have undergone incipient to weak metamorphism, and quartz veins are common. Incipient foliation is developed in the clay-slate. Alternation in grade of metamorphism is due to structure and/or rock susceptibility (p. 15).

This well penetrated the Ouachita belt in the interior part of the frontal zone; the sequence is tentatively identified as very weakly metamorphosed Tesnus.

X-ray data.—I > Ch; 10/7 ∼ 0.7; F = 20; SR = 4.0. Absence of kaolinite and relatively high SR tend to confirm the Tesnus identification.

References.—Kleihege (1948, pp. 25–26).

Personal communication: August Goldstein, Jr., Bell Oil and Gas Company, 1959; R. D. Woods, Humble Oil & Refining Company, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Terrell.

Well name.—Transcontinental Oil Company (Ohio) No. 1 Goode.

Location.—Section 26, block 161, GC&SF survey; 2,152 feet FEL, 330 feet FSL; 26 mi. SE of Sheffield.

Elevation.—2,405 feet. *Total depth.*—9,140 feet. *Completed.*—1937.

Top of Paleozoic rocks.—680 feet. *Elevation of Paleozoic rocks.*— +1,725 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3005, 3700+, 5470–80.

Description of Paleozoic rocks.—Galley (1957) noted top of Leonard, 680 feet; top of Wolfcamp, 3,100 feet; total depth 9,140 feet, in Wolfcamp. Goldstein (1955) described this well as normal foreland facies.

Samples at 3,700+ and 4,570 to 4,580 feet are dark carbonaceous pyritic silty shale; silicified fossil debris is present at 4,570 to 4,580 feet. The 3,005-foot sample appears to be a contaminant in that it is a sericitic dolomitic metaquartzite showing low-grade metamorphism with a high shearing element. Such a rock is very unlikely to occur in the No. 1 Goode.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. E. Galley, Shell Oil Company, 1957; August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Terrell.

Well name.—Williams, Calvert, and Brown No. 1 George M. Snowden (also known as E. T. Williams et al. No. 1 Cowden, No. 1 Snowden, or No. 1 Robertson).

Location.—Section 71, block D10, TCRR survey; 1,320 feet FNL, 2,640 feet FWL; 7 mi. SE of Sanderson.

Elevation.—2,442(?), 2,504(?) feet. *Total depth.*—3,150(?), 3,145(?) feet. *Completed.*—1927.

Top of metamorphic rocks.—1,385 feet. *Elevation of metamorphic rocks.*— +1,057(?) feet, +1,119(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1385, 1443, 1485, 1515, 1575, 1670, 2200, 2660, 2725 (3). SHELL OIL COMPANY: 1295, 1424(?), 1450, 1452, 1648, 1750, 1910, 1670, 2200, 2325, 2400, 2560, 2650, 2735 (3), 2935, 2960 (2), 3142–45 (5).

Description of metamorphic rocks.—Sellards (1933) stated that samples examined from 3,150 feet are schistose shale and that "the log" reports quartz and calcite veins in more or less altered shale from 2,685 feet to bottom of the well; he gave an elevation of 2,430 feet and a total depth of 3,150 feet. Woods (1955) reported top of the Paleozoic rocks near 1,400 feet and said that first samples studied at 1,423 feet are metamorphosed. Goldstein (1955) reported probable base of Cretaceous and top of Paleozoic at 1,440 feet. Kleihege (1949) described the sequence as follows: 1,385 to 1,425 feet, very fine-grained glossy variegated schist or phyllite; 1,430 to 1,800 feet, black calcareous glossy graphitic to carbonaceous phyllite cut by quartz-calcite veinlets; 1,443 feet, carbonaceous slaty limestone and marble; 1,585 feet, recrystallized limestone containing opaque carbonaceous impurities; 1,860 feet, glossy black carbonaceous phyllite; 1,900 and 2,190 feet, glossy black calcareous phyllite; 2,280 feet, glossy black phyllitic slate; 2,315 to 2,600 feet, calcareous black phyllite showing a decrease in metamorphism to fine-textured black slate; 2,630 to 2,640 feet, black phyllitic slate; 2,645 to 2,785 feet, glossy calcareous fine-textured phyllitic slate; 2,725 feet, slaty carbonaceous limestone showing only slight metamorphism.

Thin section study shows a sequence of very fine-grained calcareous and dolomitic metaquartzite, commonly graphitic, feldspathic, locally rutiliferous, sericitic, chloritic, with lesser amounts of fine-grained quartzose dolomite and calcite marble; there is abundant vein quartz in the cuttings. Fine grain size suggests these rocks might be metachert, but the presence, locally, of abundant feldspar in the quartz mosaic suggests that the fine grain size is due to crushing of an originally feldspathic rock. Metamorphism is low grade with a strong shearing component and possibly a high metasomatic element; structures are (1) foliation expressed by stretched quartz and calcite grains and parallel streaks of graphitic material, (2) suturing of quartz contacts, and (3), locally, microfolding and contortion.

This well penetrated sheared metamorphic rocks in the interior zone of the Ouachita belt and marks a salient of the interior zone.

X-ray data.—None.

References.—Kleihege (1948, pp. 36–37); Sellards (1933, p. 190).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; R. D. Woods, Humble Oil & Refining Company, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Travis.

Well name.—Tom Birdwell Water Well.

Location.—West Lake Hills, near Austin.

Elevation.—740 feet. *Total depth.*—1,043 feet. *Completed.*—1946.

Top of Paleozoic rocks.—1,013 feet. *Elevation of Paleozoic rocks.*— −273 feet.

Thin section coverage (depth in feet.)—BUREAU OF ECONOMIC GEOLOGY: 1023–43.

Description of Paleozoic rocks.—H. J. Plummer (Bur. Econ. Geol. files) described this sequence as brown schistose shale and brown sandstone. Thin section study shows dark angular calcareous chloritic sericitic siltstone veined by quartz; metamorphism is incipient.

This well penetrated dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Travis.

Well name.—Boy Scout Water Well.

Location.—J. Jett survey; 300 feet from side of Bull Creek, near mouth.

Elevation.—508± feet. *Total depth.*—852 feet. *Completed.*—Before 1938.

Top of Paleozoic rocks.—852 feet. *Elevation of Paleozoic rocks.*— -344± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—A U. S. Geological Survey sample log shows "Smithwick shale" at the bottom of the hole. From the location, it is probable that this well penetrated incipiently to very weakly metamorphosed dark clastic rocks in the interior part of the Ouachita belt.

X-ray data.—None.

References.—Files of U. S. Geological Survey, Ground Water Branch, Austin, Texas.

County.—Travis.

Well name.—Brewster and Bartle No. 1 Tucker.

Location.—W. Wells survey; 2 mi. SSE of Manor.

Elevation.—608 feet. *Total depth.*—4,506 feet. *Completed.*—ni.

Top of Paleozoic rocks.—3,840 feet. *Elevation of Paleozoic rocks.*— -3,232 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3869–99, 4024, 4207–38, 4345, 4400, 4500.

Description of Paleozoic rocks.—The sequence penetrated in this well is composed of dark, fine- to coarse-grained, angular, poorly sorted, feldspathic quartz metasandstone (low rank) containing abundant fragments of chert, phyllite, and metaquartzite, dark, angular, micaceous low-rank metasiltstone, and dark metashale. All of the rocks contain streaks and lumps of opaque matter which appears to be mostly carbonaceous but locally resembles bituminous matter. Quartz, quartz-bitumen, and calcite veinlets are common. The large amount of opaque matter makes it difficult to assess the degree of metamorphism; it appears to be incipient to very weak. Reconstituted sericite and chlorite occur in the matrix, and both mica and carbonaceous matter are bent around large quartz grains (incipient augen). The sandstones (graywackes) in this sequence contain abundant metamorphic rock fragments and appear to be a "dumped" tectonic sediment deposited close to an area of tectonism.

This well encountered incipiently to very weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 ~ 0.5; F = 20; SR = 6.0.

References.—Samples are in Bureau of Economic Geology Well Sample Library.

County.—Travis.

Well name.—City of Austin No. 1 Blunn Creek (water well).

Location.—I. Decker survey; East Live Oak Street and Sunset Lane, Austin, Texas.

Elevation.—538 feet. *Total depth.*—2,246 feet. *Completed.*—1932.

Top of Paleozoic rocks.—2,213± feet. *Elevation of Paleozoic rocks.*— -1,675± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2246.

Description of Paleozoic rocks.—Sellards (1933) reported black indurated "much squeezed" shale and black quartzite cut by calcite veins; he stated that top of Paleozoic is 2,200± feet. A single sample from 2,246 feet examined in thin section is siliceous clay-slate containing carbonaceous or graphitic material and extensively veined with quartz; metamorphism is incipient to very weak and the rock shows incipient foliation.

This well penetrated dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Sellards (1933, p. 191).
Files of the U. S. Geological Survey, Ground Water Branch, Austin, Texas.
Core fragment from 2,246 feet is in Bureau of Economic Geology Well Sample Library.

County.—Travis.

Well name.—Cooke Water Well No. J-22 (also known as C. R. Franklin No. 1 George Cooke; possibly the same as Waldron et al. No. 1 Travis Cooke).

Location.—James M. Tribble survey; 0.15 mi. FEL, 0.6 mi. FNL.

Elevation.—775± feet. *Total depth.*—1,835 feet. *Completed.*—1931.

Top of Paleozoic rocks.—1,070 feet. *Elevation of Paleozoic rocks.*— -295± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1690 (2), 1733, 1785.

Description of Paleozoic rocks.—The sequence is described in the Bureau of Economic Geology files as dark gray laminated dense somewhat schistose shale, black hard dense siltstone, and hard medium-grained sandstone. Old logs give conflicting data, e.g., top of Paleozoic, 1,610 feet; total depth, 1,790 feet.

The sequence is composed of dark very finely micaceous and chloritic carbonaceous metashale and fine-grained, angular, poorly sorted, micaceous and chloritic feldspathic silty low-rank quartz metasandstone locally containing fragments of slate, chert, and stretched quartz mosaic; dark argillaceous cryptocrystalline chert occurs in the 1,785-foot interval. Metamorphism is very weak; there is incipient foliation.

This well penetrated very weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Files of U. S. Geological Survey, Ground Water Branch, Austin, Texas.
Bureau of Economic Geology files.

County.—Travis.

Well name.—Cypress Creek Drilling Association No. 1 Romberg (also known as Jones No. 1 Romberg).

Location.—J. M. Miller survey; 8 mi. N, 25 mi. W of Austin.

Elevation.—800 feet (from topographic map). *Total depth.*—1,560 feet. *Completed.*—1927.

Top of Paleozoic rocks.—300± feet. *Elevation of Paleozoic rocks.*— +500± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 834, 1340.

Description of Paleozoic rocks.—Sellards (1931b) reported black shale at 834 feet. Thin section examination shows angular, tightly packed, fairly well-sorted, quartz siltstone and micaceous silty shale. The rocks show no metamorphism; probably they are Atoka.

This well probably penetrated foreland rocks within the frontal boundary of the Ouachita belt (Pl. 2).

X-ray data.—None.

References.—Sellards (1931b, p. 823).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Travis.

Well name.—Davenport Ranch Water Well.

Location.—8,000 feet northeast of St. Stephens School, 6 mi. NW of Capitol in Austin.

Elevation.—595 feet. *Total depth.*—1,127 feet. *Completed.*—1951(?).

Top of Paleozoic rocks.—931 feet. *Elevation of Paleozoic rocks.*— -336 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Adkins (U. S. Geol. Surv. files) described samples from this well as follows: 862 to 875 feet, sand, sandstone, and Ellenburger-type chert plus weathered brown shale of Paleozoic type—probably basal Cretaceous; 914 to 920 feet, angular sand and chert fragments, quartz, and dolomite; 920 to 922 feet, chalcedonic chert and sandstone—possibly Cretaceous conglomerate or Paleozoic; 931–965, 1,000–1,030, 1,030–1,070, 1,070–1,085, 1,095–1,123 feet, all black hard Paleozoic shale—Carboniferous or older; it is harder and more indurated than outcropping Smithwick shale.

On the basis of Adkins' description and the location, this well probably encountered incipiently to very weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Files of the U. S. Geological Survey, Ground Water Branch, Austin, Texas.

County.—Travis.

Well name.—C. R. Franklin No. 1 B. J. Reimers.

Location.—J. C. Little survey.

Elevation.—1,008 feet. *Total depth.*—835 feet. *Completed.*—1932.

Top of Paleozoic rocks.—469 feet. *Elevation of Paleozoic rocks.*— +539 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 525–55, 575–85, 585–90, 620–40, 670–80, 680, 695–710, 715–30, 735, 820, 837, 937.

Description of Paleozoic rocks.—Sample descriptions in the files of the Bureau of Economic Geology report gray dense metamorphosed shale, dark hard gray siltstone, and gray hard dense quartzitic sandstone.

The sequence is composed of very fine-grained, angular to subround, very poorly to poorly sorted, argillaceous silty quartz sandstone, locally calcareous, dark silty shale, and angular, micaceous and chloritic siltstone. Quartz and calcite veins are common and bituminous material is present. These rocks cannot be positively identified. Contortion, microfolding, and incipient to very weak metamorphism indicate that the sequence is within the Ouachita belt. The rocks are tentatively labeled Atoka(?) (see Summerow No. 1 Reimers, p. 316).

X-ray data.—I > Ch > ML > K(?); 10/7 ~ 1.1; F = 20; SR = 1.6.

References.—Bureau of Economic Geology files.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Travis.

Well name.—H. E. Goff No. 1 Basdall Gardner (Basdall Gardner No. 1 Oil Test).

Location.—Jose A. Ybarbo survey; 7 mi. S of Leander.

Elevation.—780± feet. *Total depth.*—730 feet. *Completed.*—1952.

Top of Paleozoic rocks.—710 feet. *Elevation of Paleozoic rocks.*— +70 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 725–30.

Description of Paleozoic rocks.—The single sample available is very dark brown shale or metashale. No identification can be made. This well penetrated the frontal zone of the Ouachita belt (Pl. 2).

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957.

County.—Travis.

Well name.—P. S. Griffiths et al. No. 1 (2?) Evans (Sunset Ranch) (also known as P. F. Griffin).[42]

Location.—Faubian(?), D&W(?) survey; 9.3 mi. SW of Leander.

Elevation.—1,024 feet (from aneroid barometer). *Total depth.*—1,500(?), 1,875(?) feet. *Completed.*—1921.

Top of Paleozoic rocks.—620 feet. *Elevation of Paleozoic rocks.*— +404± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 500–600 (2), 600, 625 (2), 630, 743, 775–800, 815, 828–40 (2), 848, 1400–1500 (2).

Description of Paleozoic rocks.—Sellards (1931b) reported as follows: "The Evans well in Travis County entered pre-Cretaceous rocks at or near a depth of 620 feet. Cores were received from this well at a depth of 789–793 feet. The rock at this depth is black non-calcareous shale alternating with gray quartzitic sandstone. The core shows bedding or cleavage planes of different steepness, the maximum being 70 degrees. The shale is much slickensided and inclusions of the shale are found in the sandstone. The rock is cut by calcite veins and by minute faults. This rock, in the opinion of Miser, represents Stanley shales." Barnes (*in* Sellards, 1933) noted very slight metamorphism.

Thin section study shows a sequence of dark, fine-grained, angular, poorly sorted, argillaceous sandstone, dark shale, and calcareous micaceous siltstone, all veined with quartz. Incipient metamorphism (development of metashale) is present in the 828 to 840-foot interval. In the 1,400 to 1,500-foot interval the sandstone contains abundant angular garnet in the heavy mineral fraction and is typical Stanley lithology.

This well penetrated Stanley in the frontal zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 ~ 0.7; F = 20.

References.—Sellards (1930; 1931b, p. 825; 1933, p. 135).
Bureau of Economic Geology files.
Samples in Bureau of Economic Geology Well Samples Library.

County.—Travis.

Well name.—Insane Asylum Water Well.

Location.—Austin, Texas (not plotted on Pl. 2; see Perry well, Blunn Creek well, pp. 315, 312).

[42] Notes in the files of the Bureau of Economic Geology indicate that there *may* be two Evans wells, the No. 1 drilled to 789 feet and the No. 2, ¼ mi. N, drilled to 1,875 feet.

Elevation.—635 feet. *Total depth.*—1,975 feet. *Completed.*—Before 1897.

Top of Paleozoic rocks.—1,800 feet. *Elevation of Paleozoic rocks.*— −1,165 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—A driller's log is given by Sellards (1930); base of Travis Peak is determined as 1,800 feet.

From its location, this well probably penetrated incipiently to weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Hill and Vaughan (1898, pp. 280–286); Sellards (1930, p. 53).

County.—Travis.

Well name.—Midcoast (B. R. Floyd) No. 1 E. A. Jones.

Location.—0.8 mi. SW of Jonestown, 0.3 mi. NW of Farm Road 1328.

Elevation.—1,000± feet. *Total depth.*—2,997 feet. *Completed.*—1953.

Top of Paleozoic rocks.—695 feet. *Elevation of Paleozoic rocks.*— +305± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 630–32, 646–50, 680–86, 695–00, 705–10, 720–25, 866–69, 935–62, 1146–76, 2997.

Description of Paleozoic rocks.—The sequence is composed of dark shale and metashale, commonly silty and sandy, some greenish siliceous shale (1146–76), and dark, fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone containing a high percentage of garnet in the heavy mineral fraction. The sample from 2,997 feet is clay-slate showing bedding cleavage at an angle of 60° to the core.

The rocks are Stanley shale; the well penetrated the frontal zone of the Ouachita belt.

X-ray data.—I > Ch > ML (3,000-foot sample, no ML); $10/7 \sim 2$; $F = 20$; $SR = 1.6$ (shallow), 2.3 (deep).

References.—Bureau of Economic Geology files.

Sample and cores are in Bureau of Economic Geology Well Sample Library.

County.—Travis.

Well name.—F. B. Perry Water Well.

Location.—S. Goocher survey; 0.5 mi. S of State Capitol, next to Driskill Hotel, Austin.

Elevation.—500± feet. *Total depth.*—2,025 feet. *Completed.*—1899.

Top of Paleozoic rocks.—1,965 feet. *Elevation of Paleozoic rocks.*— −1,465± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic or metamorphic rocks.—From the location, this well probably penetrated incipiently to very weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Files of U. S. Geological Survey, Ground Water Branch, Austin, Texas.

County.—Travis.

Well name.—G. L. Reasor No. 1 Jesse Ezell.

Location.—M. M. Bain survey; 10 mi. SE of Austin.

Elevation.—250 feet. *Total depth.*—3,309 feet. *Completed.*—1952.

Top of Paleozoic rocks.—3,080 feet. *Elevation of Paleozoic rocks.*— −2,830 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2790–00, 2890–00, 2990–00, 3090–00, 3140–50 (2), 3190–00, 3240–50 (2), 3300–10 (2).

Description of Paleozoic rocks.—The sequence is mostly dark carbonaceous sericitic clay-slate and dark calcareous carbonaceous micaceous quartz low-rank metasandstone. The degree of metamorphism is difficult to assess because of the abundant opaque matter, but it appears to range from incipient to very weak; incipient foliation and slaty cleavage are present. The cuttings of Paleozoic rocks are mixed with abundant olivine basalt (locally termed "serpentine") which resembles the late Cretaceous-Tertiary intrusive rocks of the Balcones fault zone. Such rock occurs higher in the section also (720 to 890 feet), and the association of basalt and Paleozoic rocks may be only contamination from higher in the well. However, the abundance of basalt cuttings with the Paleozoic rocks suggests that

the basalt intrudes Paleozoic rocks in the boring as well as Mesozoic rocks higher in the section.
This well penetrated very weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 ~ 1.1; F = 20 and 24(?); SR = 5.9.

References.—Samples in Bureau of Economic Geology Well Sample Library.

County.—Travis.

Well name.—St. Stephens School Water Well.

Location.—Antonio Rodriquez survey; 0.5 mi. FSL, 0.3 mi. FEL; 1 mi. N of Lone Tree triangulation station.

Elevation.—770±(?) feet. *Total depth.*—1,004 feet. *Completed.*—1949.

Top of Paleozoic rocks.—900(?), 990(?) feet. *Elevation of Paleozoic rocks.*— -130±(?), -220±(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 990–1004 (2).

Description of Paleozoic rocks.—H. J. Plummer (Bur. Econ. Geol. files) described this sequence as hard gray sandstone and schistose shale. The single sample examined is composed of very dark shale and fine-grained, angular, poorly sorted, argillaceous micaceous quartz low-rank metasandstone; the rocks are veined with quartz and calcite. Metamorphism is incipient to very weak.
This well penetrated very weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Files of U. S. Geological Survey, Ground Water Branch, Austin, Texas.
Bureau of Economic Geology files.

County.—Travis.

Well name.—E. D. Summerow No. 1 Reimers.

Location.—J. C. Little survey; 23 mi. W, 6 mi. N of Austin.

Elevation.—800 feet (from topographic map). *Total depth.*—1,274 feet. *Completed.*—1926 and 1932.

Top of Paleozoic rocks.—266 feet. *Elevation of Paleozoic rocks.*— +534± feet.

Thin section coverage (depth in feet.).—BUREAU OF ECONOMIC GEOLOGY: 1140, 1243.

Description of Paleozoic rocks.—Notes in the Bureau of Economic Geology files describe the sequence as dark gray shale and quartzite. Sellards (1931b) reported black shale. Goldstein (1955) reported that the first sample at 650 feet is in Pennsylvanian and the last sample, 1,243 feet, is also in Pennsylvanian; he tentatively identified the sequence as foreland facies.
The two samples available for study are fine-grained chloritic micaceous feldspathic quartz sandstone and silty micaceous metashale. Identification of this sequence is uncertain both in this well and in Franklin No. 1 Reimers immediately to the south (p. 313); the deformation noted in Franklin No. 1 Reimers and the incipient metamorphism observed in both wells indicate that they are within the margin of the structural belt. These beds may be either Stanley or Atoka; on the basis of the X-ray determinations they are tentatively identified as Atoka(?).

X-ray data.—Mixed layer illite-montmorillonite shale of foreland type.

References.—Sellards (1931b, p. 823).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Travis.

Well name.—Woodward and Company No. 1 Nelson.

Location.—P. C. Harrison survey; 3,750 feet FNWL, 5,650 feet FNEL.

Elevation.—567 feet, derrick floor. *Total depth.*—3,771 feet. *Completed.*—1955.

Top of metamorphic rocks.—3,730 feet. *Elevation of metamorphic rocks.*— -3,163 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3660–70, 3740–50.

Description of metamorphic rocks.—The samples examined are dark, fine- to medium-grained, angular to subround, poorly sorted, carbonaceous micaceous silty quartz metasandstone (graywacke) showing weak metamorphism with a high shearing component. The rocks show incipient foliation, and micaceous minerals are bent around larger grains which form incipient augen. Rock fragments, quartz, and feldspar are set in a fine foliated matrix of sericite, chlorite, and fine quartz.

This well penetrated highly sheared weakly metamorphosed rocks of the black slate belt in the interior zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 ∼ 0.6; F = 20; SR = 8.5.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1957.

County.—Uvalde.

Well name.—Bernard Einstoss No. 1 Roswell Wardlaw.

Location.—R. Middleton survey; 1,000 feet SE of N cor. of Jas. Goucher survey, thence 500 feet NE; 10 mi. E of Montell.

Elevation.—1,792 feet. *Total depth.*—2,515 feet. *Completed.*—1941.

Top of Paleozoic rocks.—1,735 feet. *Elevation of Paleozoic rocks.*— +57 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 838–44 (2), 1853–57, 2044–48, 2093–96, 2196–2205.

Description of Paleozoic rocks.—Barnes (Bur. Econ. Geol. files) reported slickensided phyllitic rocks in the interval 1,971 to 1,973 feet.

The sequence is composed of (1) fine- to medium-grained, angular, very poorly sorted, calcareous argillaceous micaceous feldspathic quartz sandstone containing abundant rock fragments; (2) fine-grained, angular, micaceous quartz siltstone; and (3) dark silty shale. Quartz, calcite, and bitumen occur in veinlets. Rock fragments include chert, quartz mosaic, shale, slate-phyllite, metaquartzite, metasiltstone, and microgranular feldspathic igneous rock. The feldspar is plagioclase; mica includes faded biotite; a large part of the quartz is bubbly and strongly undulose. Zircon is the only common heavy mineral.

These rocks possess many characteristics of Mississippian-Pennsylvanian rocks of Ouachita facies. The alternative hypothesis is that the rocks are foreland basin rocks, probably of Atoka age, located close to or within the structural belt and derived from an uplift of Ouachita facies rocks immediately to the south. In either case, this well is within or very close to the front of the structural belt. The overall texture and mineralogy and the presence of quartz, calcite, and bitumen veins suggest that these rocks are of Ouachita facies.

X-ray data.—I > Ch; 10/7 ∼ 3; F = 20; SR = 2.3. The absence of kaolinite suggests Ouachita facies.

References.—Bureau of Economic Geology files.
Personal communication: R. P. Maner, Shell Oil Company, 1959.

County.—Uvalde.

Well name.—Humble Oil & Refining Company No. 1 R. L. Anderson.

Location.—J. J. Guerra survey; 6,000 feet FSWL, 2,850 feet FSEL; 4 mi. E of Uvalde.

Elevation.—961 feet. *Total depth.*—5,015 feet. *Completed.*—1934.

Top of Paleozoic rocks.—3,482 feet. *Elevation of Paleozoic rocks.*— -2,521 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 3470–80, 3480–82, 3628–31, 3675–78, 3787–89, 3819–21, 4094, 4122, 4140–50, 4150–52, 4449–52, 4884, 4886, 4918–21, 4955–57, 6264–73. PAN AMERICAN PETROLEUM CORPORATION: 4680–85, 4918, 5806. BUREAU OF ECONOMIC GEOLOGY: 4075–80, 4100–05, 4995–00.

Description of Paleozoic rocks.—Goldstein (1955) reported top of Paleozoic Ouachita facies (Pennsylvanian?), 3,460 feet; last sample, 5,000 feet, in Pennsylvanian (?) Ouachita facies.

Petrographic study shows a sequence of dark silty shale and fine-grained, angular, poorly sorted, feldspathic quartz sandstone; locally, the rocks are metamorphosed to metashale, clay-slate, and chlorite-sericite slate, and to low-rank metasandstone; the sandstones are commonly quartzitic and locally contain abundant metamorphic rock fragments; quartz and calcite veins are common. Metamorphism ranges from none to incipient to very weak and weak without any pronounced directional structures. The interval 4,650 to 4,685 feet contains olivine basalt, and there are numerous intrusions cropping out on the surface in the general area. Possibly the variations in degree of metamorphism are the result of local thermal metamorphism by igneous intrusions. The rocks appear to be upper Paleozoic Ouachita facies (Stanley-Tesnus?); Hazzard (1958) noted that cores show steeply dipping beds.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—I > Ch > K; ML = Tr; 10/7 ∼ 2; F = 20.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; R. T. Hazzard, Gulf Oil Corporation, 1958.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Uvalde.

Well name.—Phantom Oil Company No. 1 M. D. Cloudt.

Location.—Section 661, GC&SF survey; 318.9 varas FSL, 162 varas FWL; 9 mi. FN, 2 mi. FW County line.

Elevation.—1,511 feet. *Total depth.*—2,710 feet. *Completed.*—1930.

Top of Paleozoic rocks.—1,690 feet. *Elevation of Paleozoic rocks.*— -179 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1696–1700, 1772, 1963–70, 1975–81, 2110–20, 2230–40 (2).

Description of Paleozoic rocks.—Getzendaner (1931) described sporadic samples as follows: 1,690, 1,938 to 1,945, 1,981 to 1,985 feet, very black shiny slickensided shale; 2,230 to 2,240 feet, gray sandstone, one fragment cut by a calcite veinlet. He concluded that the age is probably Pennsylvanian.

Petrographic examination shows that the sequence is composed of dark, fine-grained, angular to subround, poorly to fairly well-sorted, calcareous to argillaceous slightly feldspathic quartz sandstone, angular to subround, poorly to well-sorted, slightly calcareous micaceous sandy siltstone, and dark shale. There is no metamorphism. The rocks are foreland facies (Atoka?).

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—I $>$ Ch $>$ ML; 10/7 $\sim$ 0.7; F $=$ 20; SR $=$ 1.7.

References.—Getzendaner (1931, pp. 95, 104–106).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Uvalde.

Well name.—The Texas Company No. 1 Mitchell.

Location.—HE&WT survey; 2,298 feet FNL, 262 feet FWL; near Utopia.

Elevation.—1,668 feet. *Total depth.*—6,503 feet. *Completed.*—1949.

Top of Paleozoic rocks.—1,272 feet. *Elevation of Paleozoic rocks.*— +396 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1284–1312, 1346–76, 1376–1407, 1589–1601, 1650–80, 1826–56, 4000–30, 5650–55, 5700–05, 6150–55, 6300–05, 6400–05, 6495–6500.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Cretaceous and top of Permian, 1,272 feet; base of Permian and top of Pennsylvanian(?), 1,745 feet; total depth 6,503 feet, in Stanley-Jackfork(?). Hazzard (1958) says that the cores show bedding inclined at about 60°.

The sequence in this well is composed of dark silty shale, very micaceous and containing carbonaceous debris in some intervals, fine-grained, angular, argillaceous micaceous quartz siltstone, and fine- to medium-grained, mostly angular, poorly to very poorly sorted, argillaceous and micaceous feldspathic quartz sandstone, locally calcareous and/or dolomitic, locally containing abundant rock fragments (quartz mosaic, chert, shale-slate, phyllite, volcanic rock, granite(?), and vein quartz); some of the samples are graywacke. The sequence is not metamorphosed; veinlets are restricted to a few fine silica veinlets and minor calcite veinlets. One sample from the 1,376 to 1,407-foot interval is a fine-grained bioclastic limestone composed predominantly of calcareous fossil fragments in a fine-grained equigranular matrix of sparry calcite; a fusulinid has been identified by Ellison (1957) as probably *Fusulina* with a range from Atoka through Strawn.

The very poor sorting and abundant rock fragments suggest "dumping" close to a tectonically active source; the provenance of these rocks appears to have been metasedimentary, volcanic, and granitic rocks. Probably the rocks penetrated in this well were derived from erosion of the Ouachita belt to the south. They are tentatively considered to be Atoka and/or Strawn. The graywacke sandstones are similar to Atokan beds found in Fish No. 1 Postell in Kinney County. The well penetrated Atoka-Strawn(?) beds of foreland basin facies close to or within the frontal zone of the Ouachita belt.

X-ray data.—I $>$ Ch $>$ K; 10/7 $\sim$ 1.2; F $=$ 20; SR $=$ 2.1; weak ML and K in the upper sample are absent in the lower sample.

References.—Personal communication: S. P. Ellison, Jr., Department of Geology, The University of Texas, 1957; August Goldstein, Jr., Pan American Petroleum Corporation, 1955; R. T. Hazzard, Gulf Oil Corporation, 1958.

County.—Uvalde.

Well name.—Transcontinental Oil Company (Benedum and Trees) No. 1 Patterson.

Location.—Isaac R. Henry survey; 20 mi. FE, 5 mi. FN County line; 24 mi. N of Uvalde.

Elevation.—1,510 feet. *Total depth.*—4,220 feet. *Completed.*—1920.

Top of Paleozoic rocks.—1,726 feet. *Elevation of Paleozoic rocks.*— -216 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1293, 1700–2450 (2), 2450 (2).

Description of Paleozoic rocks.—Getzendaner (1931, p. 95) described samples from 1,700, 2,400, and 2,450 feet as hard black finely micaceous shale and compared them to Humble No. 1 Thompson in Bandera County; he referred them to the Pennsylvanian. Notes in Bureau of Economic Geology files describe the section 1,700 to 2,450 feet as deformed dark to black indurated shale, locally sandy, and not of Ouachita facies.

Petrographic examination shows a sequence of dark silty shale and very fine-grained, angular to subround, fairly well-sorted, silty quartz sandstone. These rocks are foreland facies.

This well penetrated upper Paleozoic foreland basin rocks north of the Ouachita belt.

X-ray data.—I > Ch > ML > K; 10/7 ~ 1.5; F = 20; SR = 1.7.

References.—Getzendaner (1931, pp. 95, 106–107).
Bureau of Economic Geology files.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Uvalde.

Well name.—Union Oil Company of California No. 1 Anderson.

Location.—Jedediah Peck survey; 10 mi. SW of Uvalde.

Elevation.—825 feet (from topographic map). *Total depth.*—3,775 feet. *Completed.*—1911.

Top of Paleozoic rocks.—3,147 feet. *Elevation of Paleozoic rocks.*— —2,322 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Notes in files of Bureau of Economic Geology describe the rock as black shale. No other data are available.

X-ray data.—None.

References.—Bureau of Economic Geology files.

County.—Uvalde.

Well name.—Universal No. 1 Mountain Eagle Ranch.

Location.—M. P. Zoto survey; 1,980 feet FNL, 1,980 feet FEL.

Elevation.—1,346 feet. *Total depth.*—2,370 feet. *Completed.*—1949.

Top of Paleozoic rocks.—1,132 feet. *Elevation of Paleozoic rocks.*— +214 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1038–44, 1150–56, 1351–56, 1450–63, 1546–60, 1634–40, 1985–90, 2135–40, 2211–15, 2230–35, 2245–50 (2).

Description of Paleozoic rocks.—The sequence is composed of (1) fine-grained, angular, poorly to very poorly sorted, argillaceous-micaceous feldspathic silty quartz sandstone sporadically calcareous, containing abundant rock fragments (shale, slate-phyllite, fine-grained chlorite schist, quartz mosaic, metaquartzite, metasiltstone, fine-grained feldspathic igneous rock, chert); (2) fine-grained, angular, argillaceous-micaceous sandy quartz siltstone, locally very micaceous; and (3) dark shale, locally silty, pyritic. Most of the quartz is strongly undulose; the matrix is clay-mica hash. The rocks are cut by veinlets of quartz, carbonate, and bitumen. One slide (2245–50) suggests incipient metamorphism.

This well apparently penetrated Mississippian-Pennsylvanian rocks of Ouachita facies in the frontal zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 ~ 1.2; F = 20; SR = 2.3.

References.—Personal communication: R. P. Maner, Shell Oil Company, 1959.

County.—Val Verde.

Well name.—Caraway No. 1 Guida Rose.

Location.—Section 2, GC&SF survey; 2,310 feet FNL, 330 feet FEL; 3 mi. FN, 8 mi. FE County line.

Elevation.—1,971 feet, derrick floor. *Total depth.*—11,590 feet. *Completed.*—1951.

Top of Paleozoic rocks.—760 feet. *Elevation of Paleozoic rocks.*— +1,211 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Young (1957) reported base of Cretaceous and top of Wolfcamp, 760 feet; top of lower Strawn limestone, 9,890 feet; top of Bend, 10,780 feet; top of Mississippian, 10,885 feet; top of Silurian, 10,940 feet; top of Montoya, 11,110 feet; top of Simpson, 11,160 feet; top of Ellenburger, 11,290 feet.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Addison Young, Phillips Petroleum Company, 1957.

County.—Val Verde.

Well name.—Caraway No. 1 Whitehead.

Location.—Section 8, block B, C&M survey; 467 feet FSL, 725 feet FWL.

Elevation.—2,088 feet, derrick floor. *Total depth.*—10,602 feet. *Completed.*—1956.

Top of Paleozoic rocks.—900± feet. *Elevation of Paleozoic rocks.*— +1,188± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sellin (1957) reported that top of Pennsylvanian brown shale is between 9,500 and 9,800 feet and top of Ellenburger is at 10,360 feet; he noted that data are poor and not reliable.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: H. A. Sellin, Magnolia Petroleum Company, 1957.

County.—Val Verde.

Well name.—Cockburn No. 1 Ingram.

Location.—Section 42, block LLL, GC&SF survey; 1,980 feet F most S'ly NL, 330 feet F most W'ly WL.

Elevation.—1,622 feet. *Total depth.*—1,885 feet. *Completed.*—1943.

Top of Paleozoic rocks.—1,700+(?) feet. *Elevation of Paleozoic rocks.*— —78±(?) feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—ni.

X-ray data.—None.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1959.

County.—Val Verde.

Well name.—Delta-Gulf (Phillips Petroleum Company) No. 1 Wilson.

Location.—Section 82, block E, GC&SF survey; 1,980 feet FNL, 1,980 feet FEL; 56 mi. N of Del Rio.

Elevation.—1,894 feet. *Total depth.*—16,456 feet. *Completed.*—1952.

Top of Paleozoic rocks.—930 feet. *Elevation of Paleozoic rocks.*— +964 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—The following stratigraphic data are reported: top of Permian, 930 feet; top of lower Strawn limestone, 13,800 feet; top of Mississippian, 14,160 feet; top of Silurian, 14,210 feet; top of Fusselman, 14,340 feet; top of Simpson, 14,520 feet; top of Ellenburger, 14,905 feet; top of Wilberns, 16,400 feet (Young, 1958).

Barnes (1958) noted that the Ellenburger sequence in this well is darker than in wells to the north and that fractures in the rock are filled with quartz; north of this well the fractures in the Ellenburger commonly are open. This may reflect Ouachita orogenic movements.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Barnes (1959, p. 660).

Personal communication: V. E. Barnes, Bureau of Economic Geology, 1958; Addison Young, Phillips Petroleum Company, 1958.

Samples in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—Douglas Oil Company No. 1 J. E. Sellars, Jr. (Sellers) (also known as Benedum and Trees No. 2 Sellars).

Location.—Section 82, block A, I&GN survey; 4,182 feet FSL, 4,182 feet FEL.

Elevation.—1,288 feet. *Total depth.*—4,192 feet. *Completed.*—1927.

Top of Paleozoic rocks.—1,860 feet. *Elevation of Paleozoic rocks.*— —572 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1820–40 (6), 1905–15, 1915–25, 1945–55, 1985–95, 2005–15 (2), 2015–20, 2044–55, 2125–30, 2150–60 (2), 2190–00, 2200–10, 2210–20

(2), 2220–30, 2240–50, 2310–20, 2550–60 (2), 2600–10, 2620–30, 2630–40, 2660–70 (2), 2740–50, 2770–80, 2780–00, 3175–80 (2), 3227, 3260–64, 3271–78, 3284–94, 3294–03 (2), 3303–15, 3343–53, 3353–67, 3378–82, 3397–3402, 3434–38 (2), 3438–41 (2), 3456–66, 3466–70, 3489–97, 3497–03, 3625–35 (2), 3745–50, 3785–3810 (2), 3835–50, 3885–00, 3915–30, 3950–60, 3990–4000, 4015–25 (2), 4035–45, 4140–45, 4145–50, 4155–60, 4160–65.

Description of Paleozoic rocks.—Kleihege (1949) made the following observations on the pre-Cretaceous sequence: 1,860 feet, clear to gray quartzite; 1,900 to 2,320 feet, slates; 3,175 to 3,500 feet, sandstones and shales; 3,800 to 4,192 feet, metamorphosed and unmetamorphosed carbonate rocks. He suggested that the alternation in degree of metamorphism is due to structural conditions but remarked that if there is no dislocation the sequence is probably Cambro-Ordovician.

Petrographic study of cuttings from this well (based on very small and fragmentary thin sections) shows the following sequence:

1. Thin sections 1820–40 to 2044–55: Fine-grained quartzose dolomite or dolomite marble and dark, very fine-grained pyritic dolomitic sericite chlorite-quartz rock, locally feldspathic; there are also fragments of pyrite-quartz-dolomite vein rock.
2. Thin sections 2125–30 to 2780–00: Very fine-grained opaque black calcareous and dolomitic graphite slate, locally siliceous, and veined by quartz and carbonate; two samples (2620–30, 2630–40) contain rod-like calcite bodies which appear to be spicules.
3. Thin sections 3175–80 to 3497–3503: Fine-grained, angular to round, fairly well-sorted to poorly sorted, tightly packed, quartzitic feldspathic quartz sandstone containing abundant shale fragments and some chert grains, locally calcareous or dolomitic, locally micaceous and argillaceous, and locally (3343–53) fossiliferous (pelmatozoan fragments, ostracod(?) fragments, fusulinids, shell fragments, and spines); both plagioclase and potassium feldspar are present and quartz grains commonly show siliceous overgrowths.
4. Thin sections 3625–35 to 4160–65 (last sample): Very fine-grained dolomitic limestone or calcilutite containing intraclasts of twinned sparry calcite and fine-grained dolomite and calcareous dolomite, commonly sandy.

The upper two units appear to be very weakly to weakly metamorphosed, although the degree of alteration is difficult to assess due to extremely fine grain size and obscuring effects of the abundant graphitic material; in some samples in the upper sequence fine fibers of sericite and chlorite occur in a non-oriented mat in an aggregate of quartz and the fabric appears to be crystalloblastic. It is difficult to determine whether or not the dolomite rock is recrystallized. There are no pronounced shearing structures, but the vein rock is commonly severely strained and fractured. The over-all lithology, the presence of what are probably spicules in some of the graphitic rocks, and the presence of very weak or weak metamorphism without strong shearing suggest that these rocks are lower Paleozoic Ouachita facies. Unit (3) above shows no effects of metamorphism; the general lithology and the fossil assemblage noted in the interval 3343–53 suggest a Mississippian-Pennsylvanian age; the degree of sorting suggests foreland facies, but the feldspar content is higher than normal in foreland facies rocks. The carbonate sequence in the bottom of the well is unmetamorphosed except for shearing in the upper part (3745–50 and 3885–3900). These rocks may be lower Paleozoic foreland facies carbonates, but their lithology is not typically Ellenburger.

The following tentative interpretation is offered: The well penetrated very weakly metamorphosed lower Paleozoic Ouachita facies rocks thrust over a foreland sequence composed of Mississippian-Pennsylvanian quartzitic feldspathic sandstones and lower Paleozoic carbonate rocks. An alternative hypothesis is that lower Paleozoic Ouachita facies rocks are thrust over upper Paleozoic sandstones of Ouachita facies, which in turn have overridden a foreland facies carbonate sequence.

X-ray data.—None.

References.—Kleihege (1948, p. 28).
Personal communication: E. A. Vogler, Shell Oil Company, 1955.

County.—Val Verde.

Well name.—East Del Rio Oil Company No. 1 Russell and Weatherby (Weatherbee).

Location.—J. I. Mitchell survey; 1 mi. E of Del Rio.

Elevation.—953 feet. *Total depth.*—3,332 feet. *Completed.*—1928.

Top of Paleozoic or metamorphic rocks.—2,800 feet. *Elevation of Paleozoic or metamorphic rocks.*—−1,847 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2837–42, 2842–51, 2851–57, 2871–83.

Description of Paleozoic or metamorphic rocks.—Descriptions of scattered samples between 3,280 and 3,310 feet show gray dolomitic limestone and quartz fragments (Bur. Econ. Geol. files). Kleihege (1949) reported that this well (he carried it as No. 1 Russell Withersbee) entered dolomite below the base of the Trinity at 2,790 feet; 2,790 feet, finely crystalline gray to neutral dolomite; 2,845 to 2,950 feet, finely crystalline ivory-colored dolomite; 3,025 to 3,180 feet, finely crystalline to medium crystalline light gray dolomite; 3,290 to 3,310 feet, light-colored poorly sorted well-cemented sandstone overlying light gray moderately crystalline dolomite. Kleihege noted that the well lies south of the zone of metamorphism but he interpreted the sequence as unmetamorphosed.

Petrographic study was difficult because of the extreme fineness of the cuttings available; a few cuttings show dolomite and quartz in a granoblastic mosaic and therefore the sequence is interpreted as composed of very finely crystalline dolomite marble—metamorphism is low grade. The origin of the abundant magnetite in the slides is not clear.

This well appears to have penetrated a low-grade metamorphic carbonate (dolomite) sequence in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Kleihege (1948, p. 51).
Bureau of Economic Geology files.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—Fenslund (Fensland) Oil Company No. 1 Abb Rose.

Location.—Section 56, block AZ, GC&SF survey; 6 mi. N of NW cor. of Kinney County; 30 mi. N of Del Rio.

Elevation.—1,865(?) feet. *Total depth.*—2,928 feet. *Completed.*—ni.

Top of Paleozoic rocks.—1,810(?), 1,935(?) feet. *Elevation of Paleozoic rocks.*— +55(?), —70(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1827–35, 1880–1935 (3), 1935–55, 1980–2010 (4), 2010–75 (2), 2428–35, 2450–75, 2425–60, 2540–2605, 2686–93, 2775–85 (2), 2810–20, 2900–15, 2915–28. SHELL OIL COMPANY: 2681 (2), 2699, 2790, 2800, 2820 (4), 2840 (2), 2850, 2880–85, 2900 (3).

Description of Paleozoic rocks.—Udden (Bur. Econ. Geol. files) described the sequence as black shale and dark gray highly indurated sandstone and suggested a correlation with the Tesnus formation. Kleihege (1949) noted that this well penetrated a pre-Cretaceous section composed of nearly 1,000 feet of black finely arenaceous shale, indurated toward the bottom of the section, with beds of clear to gray quartzite in the bottom one-third of the sequence; he believed that the No. 1 Abb Rose is adjacent to the belt of metamorphosed sedimentary rocks.

Petrographic study shows that the rocks are mostly dark slightly sandy and silty shale, locally dolomitic, dark dolomitic carbonaceous micaceous siltstone, and dark, very fine-grained, angular to subround, fairly well- to well-sorted, dolomitic quartz sandstone, commonly feldspathic and micaceous, locally calcareous, carbonaceous (or bituminous?), and locally veined with quartz. The presence of quartz veins and the X-ray data suggest proximity to the Ouachita belt but general lithology indicates that the rocks are foreland facies.

This well is close to the Ouachita front; probably it penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—$I > Ch$; $10/7 \sim 1$; $F = 20$; $SR = 3.3$. Absence of kaolinite and mixed-layer clay suggests these rocks may be Ouachita facies.

References.—Kleihege (1948, p. 23).
Bureau of Economic Geology files.
Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—Hiawatha Oil Company (Benedum and Trees) No. 1 Sellars (Sellers).

Location.—Section 1031, block A, GC&SF survey; 1,200 feet FSL, 5,800 feet FWL.

Elevation.—1,221(?), 1,205(?) feet. *Total depth.*—3,502 feet. *Completed.*—1927.

Top of metamorphic rocks.—1,700± feet. *Elevation of metamorphic rocks.*— -479(?), -495(?) feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 1725 (2), 1725–35 (5), 1750–60 (3), 1815 (4), 1920, 2000, 2050 (2), 2641 (4), 2650, 2708, 2725 (3), 2780, 3009–14, 3035–42 (2), 3070 (5), 3152–58, 3192–00, 3200–04 (2), 3210–15 (6), 3215–22, 3231–40, 3248–55, 3261–70 (2), 3270–78 (2), 3284–89, 3433–46, 3476–81, 3503.

Description of metamorphic rocks.—Kleihege (1949) reported 700 feet of quartzite overlying 1,000 feet of quartz-chlorite schist. Goldstein (1955) described chlorite phyllite and metaquartzite and noted a similarity in degree of metamorphism to the metasedimentary rocks of the Luling area.

The upper sequence penetrated in this well (including samples from 1,725 to 1,815 feet with skips) is fine-grained dolomite marble, commonly calcareous and quartzose, locally pyritic and sericitic, fine-grained dolomitic calcite marble, and very fine-grained finely micaceous dolomitic metaquartzite or metachert. Below is a sequence (samples from 1,920 to 2,050 feet) of fine-grained slightly sericitic calcareous metaquartzite and fine-grained dolomitic sericitic quartzose calcite marble; the quartz is severely strained and grain contacts are sutured. Dolomite rhombs in the marbles are extensively twinned and calcite grains are commonly twinned, stretched, and deformed; rude foliation is expressed by stretched grains and oriented sericite fibers. Metamorphism is low grade with a pronounced shearing component, and the rocks are similar to those encountered in many wells in the interior zone of the Ouachita belt.

At 1,815 feet the sample is composed of unaltered fine-grained dolomite, and at 2,000 feet there is a fragment of fine-grained calcareous dolomite. The presence of these unaltered rocks in the sheared sequence is not readily explainable—possibly they are cavings.

From 2,050 to 2,641 feet there is a sample skip. Samples from 2,641 through 3,433 to 3,446 feet (with skips) are metavolcanic rocks. This lower sequence is composed mainly of foliated microgranular to cryptocrystalline sericite (muscovite)-chlorite-quartz-alkali feldspar rocks, locally containing epidote, dolomite, biotite, and commonly cut by quartz and calcite veins. Some rocks contain relict albite-oligoclase or microcline phenocrysts and/or coarser lenses of quartz-alkali feldspar in the fine granular mass. Most of the rocks are metarhyolite but some may be intermediate varieties. Metamorphism is difficult to assess—it appears to be a low grade regional metamorphism with a strong metasomatic element. This metavolcanic sequence is not commonly found in the Ouachita structural belt; to the east in Kinney County metarhyolite is overlain by lower Paleozoic dolomite in Havoline No. 1 Weatherby and is probably Precambrian (p. 284). The sample from 3,503 feet is fine-grained chlorite-actinolite-augite-plagioclase rock (not foliated); this altered microgabbro may be part of the Precambrian(?) igneous sequence, or it may be a younger intrusion in the metavolcanic sequence. Probably the upper sheared sequence is part of the Ouachita belt which has been overthrust from the south. The following interpretation is offered: The well passed out of Mesozoic rocks, penetrated allochthonous sheared marbles of the interior zone of the Ouachita structural belt, intersected an over thrust, and bottomed in Precambrian metavolcanic rocks.

X-ray data.—None.

References.—Kleihege (1948, p. 44).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; E. A. Vogler, Shell Oil Company, 1955.

County.—Val Verde.

Well name.—Humble Oil & Refining Company No. 1 Mills Mineral Trust.

Location.—Section 128, block 1, I&GN survey; 802 feet FSL, 2,174 feet FEL; 2 mi. W of Pandale, 2,000 feet SW of Owens No. 1 Mills.

Elevation.—1,812 feet, derrick floor. *Total depth.*—17,525 feet. *Completed.*—1957.

Top of Paleozoic rocks.—180 feet. *Elevation of Paleozoic rocks.*— +1,632 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Woods (1957) reported the following sequence: top of Permian, 180 feet; top of Pennsylvanian, 3,420 feet; top of lower Strawn, 14,165 feet; top of Hunton, 14,715 feet; top of Simpson, 15,180 feet; top of Ellenburger, 16,187 feet.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: R. D. Woods, Humble Oil & Refining Company, 1957.

County.—Val Verde.

Well name.—Humble Oil & Refining Company No. 1 Emma Wardlaw.

Location.—Section 53, block D, GC&SF survey; 15 mi. SE of Juno.

Elevation.—1,998 feet. *Total depth.*—15,295 feet. *Completed.*—1956.

Top of Paleozoic rocks.—1,090 feet. *Elevation of Paleozoic rocks.*— +908 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Bybee (1959) reported the following information: 1,090 to 12,200 feet, dark shale and sandy shale of Permian age; 12,200 to 12,670 feet, hard quartzitic sandstone of Permian age; 12,670 to 13,900 feet, dark shale of which the lower part is probably Pennsylvanian; 13,900 to 14,210 feet, Lower Pennsylvanian Strawn or Bend(?) limestone; 14,210 to 14,240 feet, Mississippian rocks; 14,240 to 14,500 feet, Devonian rocks; 14,500 to 14,730 feet, Simpson rocks; 14,730 to 15,295 feet, Ellenburger dolomite.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1958; R. W. Bybee, Humble Oil & Refining Company, 1959.

County.—Val Verde.

Well name.—Hurlbut No. 1 Bluff Creek Ranch.

Location.—Section 3, block 5, I&GN survey.

Elevation.—1,198 feet. *Total depth.*—3,485 feet. *Completed.*—1954.

Top of Paleozoic and/or metamorphic rocks.—2,490 feet. *Elevation of Paleozoic and/or metamorphic rocks.*— -1,292 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 2690–2730, 2930–70, 3310–30, 3360–80, 3440–60.

Description of Paleozoic and/or metamorphic rocks.—Vogler (1955) reported top of Hosston, 2,410 feet; top of Ellenburger, 2,490 feet; top of granite, 3,480 feet. Masson (1955) reported the following brief descriptions: 2,720 to 2,730 feet, fine- to medium-grained limestone, no metamorphism; 3,390 to 3,430 feet, medium- to coarse-grained limestone and dolomite, locally weakly sheared, shows slate-zone metamorphism; 3,450 to 3,480 feet, quartzite and siliceous calcphyllite showing phyllite zone metamorphism.

Petrographic studies indicate the following lithologies: 2,690 to 2,730 feet, fine-grained equigranular dolomite showing slight deformation and blurring of grain boundaries, and cut by strained and deformed quartz veinlets; 2,930 to 2,970 feet, fine-grained equigranular quartzose dolomite with both dolomite and calcite veinlets extensively twinned; 3,310 to 3,330 feet, graphitic (?) metamorphosed dolomite with a rude foliation and sericitic dolomitic quartzite; 3,360 to 3,380 feet, pyritic metamorphosed dolomite with sericite developed in shear zones; 3,440 to 3,460 feet, feldspathic dolomitic quartzite showing granulation and crushing along grain boundaries.

This well is difficult to interpret. Operating geologists generally consider the dolomite rocks as Ellenburger; it should be pointed out, however, that if these beds are Ellenburger, they are not normal Ellenburger. The lower part of the "Ellenburger" sequence is metamorphosed and rudely foliated; foliation is expressed in orientation of long dimensions of grains and metamorphism is weak to low grade. The samples from 3,310 to 3,330, 3,360 to 3,380, and 3,440 to 3,460 feet are part of the same general sequence. It is difficult to relate the apparently unmetamorphosed carbonate rocks at 2,690 to 2,730 and 2,930 to 2,970 feet to the underlying metamorphosed carbonate rocks. It was reported that "granite" was encountered between 3,480 and 3,485 feet (total depth) but no samples were located for this interval.

Inspection of the map (Pl. 2) shows that this well lies between the Ouachita front and Havoline No. 1 Weatherby (p. 284). In this area, rocks south of the Ouachita front are dislocated highly sheared metamorphic rocks of the interior zone. In Havoline No. 1 Weatherby, siliceous or quartzose lower Paleozoic dolomite rests on metarhyolite of probable Precambrian age which is part of the Devils River uplift—an area of high-standing Precambrian rocks. The Ouachita belt was crushed against the Devils River uplift and the lower Paleozoic carbonate beds that mantle the buttress were deformed and slightly metamorphosed. Here, then, foreland facies rocks are slightly metamorphosed.

The No. 1 Bluff Creek Ranch well probably penetrated deformed and slightly metamorphosed lower Paleozoic foreland facies carbonate rocks in an area of great structural complexity north of the allochthonous interior zone of the Ouachita belt. If "granite" was penetrated in the bottom of this well, it is probably Precambrian.

X-ray data.—None.

References.—Personal communication: P. H. Masson, Humble Oil & Refining Company, 1955; E. A. Vogler, Shell Oil Company, 1955.

County.—Val Verde.

Well name.—Husky Oil Company No. 1 Rose-Robertson.

Location.—Section 83, block N, GH&SA survey; 660 feet FSL, 1,980 feet FEL; 1 mi. S of Comstock.

Elevation.—1,580 feet. *Total depth.*—2,426 feet. *Completed.*—1951.

Top of metamorphic rocks.—2,170 feet. *Elevation of metamorphic rocks.*— -590 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 2330–40 (5), 2400–08. BUREAU OF ECONOMIC GEOLOGY: depth unknown.

Description of metamorphic rocks.—The samples available are very fine-grained actinolitic chlorite-epidote-sericite schist and very fine-grained actinolite-epidote schist, locally chloritic and calcareous. Metamorphism is low grade with a very strong shearing element; structures are foliation, contortion, and fracture cleavage. The original rock may have been basaltic.

This well penetrated the interior zone of the Ouachita belt and/or Precambrian metavolcanic rocks of the Devils River uplift.

X-ray data.—None.

References.—Personal communication: E. A. Vogler, Shell Oil Company, 1955.

County.—Val Verde.

Well name.—Independent Operator No. 1 L. Rust (Whitehead) (also known as W. H. Bowers No. 1 Bluff Creek Ranch, Huber Oil Syndicate No. 1 Rust, Permian Basin Operators No. 1 Rust, Permian Basin Operators No. 1 Whitehead).

Location.—Section 30, block 4, I&GN survey; 8 mi. E of Del Rio.

Elevation.—1,177 feet, derrick floor. *Total depth.*—5,430 feet. *Completed.*—1924(?).

In metamorphic rocks at 2,420 feet. *Elevation of metamorphic rocks.*— $<$ –1,243 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2420, 2530, 2774, 2780, 2836, 3070, 3110, 3150, 3240, 3250.

Description of metamorphic rocks.—Kleihege (1949) interpreted the sequence in this well as follows: 2,700 to 2,830 feet, gray to black finely crystalline slaty limestone; 2,830 to 3,080 feet, slightly more metamorphosed than above and composed of white finely crystalline limestone, black slate, and glossy partly marmorized slaty limestone; 3,080 to 3,120 feet, gray shaly limestone with a microgastropod fauna as carbonaceous molds; 3,155 to 3,220 feet, finely crystalline slaty dark gray glossy limestone; 3,280 to 3,420 feet, phyllitic marble and black slate; 3,510 to 3,710 feet, gray slaty finely crystalline marble.

Petrographic study of very fine cuttings shows that the sequence is made up mostly of fine-grained calcite marble with minor dolomitic calcite marble and dolomite marble; graphite, commonly associated with pyrite, occurs in cloudy masses and opaque patches. Metamorphism is low grade; foliation is expressed in elongate, stretched calcite and quartz grains and long smeared-out streaks of sericite. There is a strong shearing element.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Kleihege (1948, p. 32).

Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—Joiner Oil Corporation No. 1 Sellars (Sellers) Bros. Ranch.

Location.—Section 59, block A, I&GN survey; 2,728 feet FEL, 2,340 feet FNL; 22 mi. W of Del Rio.

Elevation.—1,296 feet. *Total depth.*—2,252 feet. *Completed.*—1940.

Top of metamorphic rocks.—1,950 feet. *Elevation of metamorphic rocks.*— –654 feet.

Thin setcion coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1940–50 (2), 1950–58 (2), 1958–70 (2), 1970–77, 1977–90, 2023–25, 2032–39, 2047–65, 2065–68, 2068–74, 2074–78, 2078–82.

Description of metamorphic rocks.—Hills (1941) remarked that "showings of gas were found in crystalline dolomite, probably Ellenburger, which underlies the Cretaceous in Joiner's Sellers No. 1 . . . This test is probably near the border of the overthrust, as another test 2 miles east passed from the Cretaceous into metamorphic rocks." Kleihege (1949) noted that the Cretaceous rocks are underlain by a clear gray quartzite (1,950 to 1,990 feet) which in turn is underlain by a finely crystalline gray tight dolomite which shows no signs of metamorphism; he places the well in the "slate zone" on the basis of location. Goldstein (1955) reported base of Cretaceous and top of Paleozoic is between 1,990 and 2,060 feet, with total depth 2,252 feet in Paleozoic dolomite.

Petrographic study shows a sequence of metaquartzite overlying fine-grained dolomite which is probably dolomite marble. The metaquartzite is a granoblastic-cataclastic rock with sutured and stretched grains; metamorphism is low grade with a strong shearing element. The underlying dolomite does not show evidence of metamorphism in the carbonate mosaic, but small patches of quartz mosaic locally show stretched grains and contain oriented sericite fibers.

This well appears to be located very close to the front of the Ouachita belt. Hiawatha No. 1 Sellers immediately to the southeast (p. 322) passed from the Cretaceous into sheared rocks of the Ouachita belt, intersected an overthrust, and bottomed in Precambrian metavolcanic rocks. Douglas No. 1 Sellars to the northeast is interpreted as having passed from Cretaceous rocks into very weakly metamorphosed Ouachita (Marathon) facies rocks thrust over a foreland facies sequence. Joiner No. 1 Sellars appears to have passed from Cretaceous rocks into an overthrust slice of sheared metaquartzite and bottomed in slightly metamorphosed dolomite (lower Paleozoic(?) Ellenburger(?)).

X-ray data.—None.

References.—Hills et al. (1941, p. 1530); Kleihege (1948, p. 27).

Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955; E. A. Vogler, Shell Oil Company, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—Killam No. 1 Babb.

Location.—Section 104, block 2, I&GN survey; 3,840 feet FSL, 1,500 feet FWL.

Elevation.—1,559 feet. *Total depth.*—3,075 feet. *Completed.*—1949.

Top of Paleozoic rocks.—800 feet. *Elevation of Paleozoic rocks.*— +759 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.— Reported as upper Paleozoic clastic rocks of foreland facies. This well is probably located north of the Ouachita front.

X-ray data.—None.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1959.

County.—Val Verde.

Well name.—Killam No. 1 Everett.

Location.—Section 138, block 1, I&GN survey; 1,800 feet FEL, 750 feet FSL.

Elevation.—1,563 feet. *Total depth.*—3,001 feet. *Completed.*—1948.

Top of Paleozoic rocks.—820 feet. *Elevation of Paleozoic rocks.*— +743 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Reported as upper Paleozoic clastic rocks of foreland facies. This well is located north of the Ouachita front.

X-ray data.—None.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1959.

County.—Val Verde.

Well name.—Killam No. 1 Parker.

Location.—Section 489, CCSD&RGNG survey; 467 feet FSL, 481 feet FWL; 8 mi. N of Del Rio.

Elevation.—1,185 feet. *Total depth.*—2,676 feet. *Completed.*—1949.

Top of metamorphic rocks.—2,390 feet. *Elevation of metamorphic rocks.*— -1,205 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2350–60, 2380–90, 2450–60, 2550–60, 2560–70, 2660–70.

Description of metamorphic rocks.—The pre-Cretaceous rocks are fine-grained dolomitic calcite marble locally containing abundant quartz in patches of mosaic (recrystallized chert?) and locally containing sheaves and plates of muscovite. The marble is transected by veinlets of extensively twinned sparry calcite, quartz, and chlorite. Metamorphism is low grade with a high shearing element; foliation is expressed by dimensional orientation of stretched grains and by mica orientation.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Addison Young, Phillips Petroleum Company, 1957.

County.—Val Verde.

Well name.—Magnolia Petroleum Company No. 1 Morrison.

Location.—Section 10, block Q-4, TCRR survey; 990 feet FNL, 1,980 feet FWL.

Elevation.—2,227 feet, derrick floor; 2,213 feet, ground. *Total depth.*—15,143 feet. *Completed.*—1956.

Top of Paleozoic rocks.—630 feet. *Elevation of Paleozoic rocks.*— +1,597 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—According to Sellin (1957) the following divisions are recognized in this well: base of Cretaceous and top of Permian, 630 feet; top of Pennsylvanian limestone, 12,180 feet; top of Devonian, 12,480 feet; top of Fusselman, 12,780 feet; top of Sylvan, 12,905 feet; top of Simpson, 13,035 feet; top of Ellenburger, 13,586 feet; top of Wilberns, 15,124 feet. The section from 630 to 12,180 feet is shale and sandstone with a few limestone beds in the basal part; the limestones disappear to the west. General opinion is changing to favor acceptance of a Wolfcamp age for this sequence. According to Barnes (1957), the Ellenburger in this well is darker than is normal in beds to the north.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: V. E. Barnes, Bureau of Economic Geology, 1957; H. A. Sellin, Magnolia Petroleum Company, 1957.

County.—Val Verde.

Well name.—Magnolia Petroleum Company No. 1 W. E. Whitehead.

Location.—Section 81, block D, GC&SF survey; 160 feet FWL, 1,600 feet FSL.

Elevation.—1,779 feet. *Total depth.*—6,725 feet. *Completed.*—1928.

Top of Paleozoic rocks.—960 feet. *Elevation of Paleozoic rocks.*— +819 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sandidge (1955) reported base of Cretaceous, 960 feet; black shale and gray sandstone to total depth. This sequence was formerly thought to be Pennsylvanian (Cannon and Cannon, 1932), but Galley (1957) suggested that it might be Wolfcamp. Kleihege (1949) remarked that the well penetrated 5,600 feet of black arenaceous shale closely resembling that found in Milham No. 1 Bassett. In the files of the Bureau of Economic Geology, a number of different terms including Gaptank(?), Strawn, and Bend have been applied to this sequence, which is described as dark sandy shale, locally bituminous, fine-grained sandstone, and rare limestone beds, locally crinoidal.

This well penetrated upper Paleozoic foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Cannon and Cannon (1932, p. 172); Kleihege (1948, p. 23).
Personal communication: J. E. Galley, Shell Oil Company, 1957; J. R. Sandidge, Magnolia Petroleum Company, 1955.

County.—Val Verde.

Well name.—C. A. Maurer No. 1 John W. Ingram.

Location.—Section 33, block S2, ELRR survey; 730 feet FEL, 2,030 feet FSL; 9 mi. N 70° E of Langtry.

Elevation.—1,564 feet. *Total depth.*—2,030(?), 2,078(?) feet. *Completed.*—1947.

Top of metamorphic rocks.—1,905(?), 1,950(?) feet. *Elevation of metamorphic rocks.*— -341(?), -386(?) feet.

Thin section coverage (depth in feet).—None.

Description of metamorphic rocks.—According to Kleihege (1949), the base of the Trinity is at 1,905 feet and immediately underneath is 5 feet of fine-grained white poorly cemented sandstone (1,905 to 1,910 feet) and 25 feet of variegated and white chert (1,910 to 1,935 feet). From 1,950 to 2,010 feet there is glossy green and red waxy textured phyllitic slate and vein quartz—the phyllite at the top of the section is composed mostly of chlorite with minor sericite and hematite causing the red color. The grade of metamorphism decreases with depth and the rock looks like a gray-green slickensided slaty shale. From 2,010 to 2,073 feet the sequence is composed of a black waxy shale ranging from slate at the top to shale at the bottom.

On the basis of location and interpreting Kleihege's descriptions, it appears that this well penetrated metamorphosed rocks in the interior zone of the Ouachita belt. The chert and sandstone directly beneath the Cretaceous are not readily explainable; the chert section suggests equivalence with Ordovician-Devonian beds of the Marathon Basin but no correlation is warranted. Possibly the sandstone is Cretaceous. The structural salient of the interior zone mapped in south-central Val Verde County is based on this well.

X-ray data.—None.

References.—Kleihege (1948, p. 41).

County.—Val Verde.

Well name.—O. O. Owens No. 1 Mills Ranch.

Location.—Section 128, block 1, I&GN survey; NE cor. of section; 4 mi. W of Pandale.

Elevation.—1,860 feet. *Total depth.*—6,780 feet. *Completed.*—1931.

Top of Paleozoic rocks.—775 feet. *Elevation of Paleozoic rocks.*— +1,085 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2883–88, 3030–53, 4032–38, 4170–78.

Description of Paleozoic rocks.—Galley (1957) reported top of Wolfcamp(?), 775 feet; total depth 6,780 feet, in Wolfcamp. Samples studied are mostly fine-grained, angular to subround and round, fairly well-sorted, calcareous quartz sandstone commonly containing partly disintegrated shale fragments. There is no metamorphism or veining.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. E. Galley, Shell Oil Company, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—Petrocel No. 1 Waldrop.

Location.—Section 27, block 5, I&GN survey; 1,200 feet FSL, 2,940 feet FWL.

Elevation.—1,263 feet. *Total depth.*—2,384 feet. *Completed.*—1952.

Top of Paleozoic rocks.—1,930± feet. *Elevation of Paleozoic rocks.*— -667± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—From its location and data from Stiles et al. (1955), this well appears to have penetrated lower Paleozoic carbonate rocks.

X-ray data.—None.

References.—Stiles et al. (1955).

County.—Val Verde.

Well name.—Phantom Oil Company (Bovaird Drilling Company) No. 1 Ingram.

Location.—Section 44, block D8, ELRR survey; 175 feet FEL, 300 feet FSL; 8 mi. N of Langtry.

Elevation.—1,494 feet. *Total depth.*—3,010(?), 3,035(?) feet. *Completed.*—1930.

Top of Paleozoic rocks.—1,605 feet. *Elevation of Paleozoic rocks.*— -111 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1665–75, 1715–25, 1755–65 (2), 1905–15, 2235–45, 2495–00, 2525–38, 2700–10, 2820–30, 2940–50.

Description of Paleozoic rocks.—Notes in Bureau of Economic Geology files describe a sequence of black shale "not much altered." Kleihege (1949) described the Paleozoic beds as very fine-textured black shales with some beds of brown to gray fine-grained sandstone; about 90 percent of the section is shale, commonly slickensided. He concluded that the well is located north of the "slate zone."

Petrographic study shows that the sequence is composed of dark shale, locally carbonaceous, micaceous, locally silty, and fine-grained, angular to subround, fairly well-sorted to poorly sorted, slightly calcareous argillaceous quartz sandstone, feldspathic in the deeper part of the well, locally containing bituminous material; the sandstone is cut by calcite veinlets in some intervals. There is no metamorphism; fabrics are clastic and bedding is the only structure observed. These rocks are tentatively identified as Pennsylvanian or Wolfcamp rocks of foreland facies; the well is probably located close to the front of the Ouachita belt.

X-ray data.—$I > Ch$; $10/7 \sim 1.2$; $F = 20$; $SR = 2.1$.

References.—Kleihege (1948, p. 23).
Bureau of Economic Geology files.

County.—Val Verde.

Well name.—Phillips Petroleum Company No. 1-A Guinn.

Location.—Section 2, BS&F survey; 2,030 feet FNL, 1,980 feet FEL; 11.4 mi. FN, 27 mi. FW County line.

Elevation.—2,066 feet, derrick floor. *Total depth.*—15,015 feet. *Completed.*—1957.

Top of Paleozoic rocks.—1,185 feet. *Elevation of Paleozoic rocks.*— +881 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Young (1957) reported base of Cretaceous and top of Wolfcamp, 1,185 feet; top of lower Strawn limestone, 11,960 feet; top of Siluro-Devonian limestone, 12,840± feet; top of Montoya, 13,180 feet; top of Simpson, 13,210 feet; top of Ellenburger, 14,050 feet.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Addison Young, Phillips Petroleum Company, 1957.

County.—Val Verde.

Well name.—Plateau Oil Company No. 1 B. S. Harrison et al.

Location.—Section 14, block 3, I&GN survey; 1,280 feet FNL, 660 feet FWL; 9 mi. E, ½ mi. N of Del Rio.

Elevation.—1,111 feet. *Total depth.*—3,507 feet. *Completed.*—1926.

Top of metamorphic rocks.—3,148(?), 2,900(?) feet. *Elevation of metamorphic rocks.*— -2,037(?), -1,789(?) feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 3100–34. BUREAU OF ECONOMIC GEOLOGY: 3215, 3485.

Description of metamorphic rocks.— Sample descriptions in the Bureau of Economic Geology files report basal sand and conglomerate of the Trinity from 2,910 to 2,940 feet, gray to red sandstone from 2,940 to 3,000 feet, and gray limestone, chert, and loose sand from 3,000 to 3,148 feet; the first fragments of metamorphic rock are reported at 3,148 feet. Sellards (1933) placed top of the Paleozoic at 3,148 feet and described the rock as talcose shale. Kleihege (1949) placed the base of the Trinity sand between 2,880 and 2,900 feet and described the succeeding sequence as follows: 2,900 to 3,025 feet, finely crystalline vari-colored limestone containing a 20-foot sandstone bed; 3,045 to 3,100 feet, light gray to orange quartzite, the lower 30 feet very fine-grained and approaching novaculite; 3,120 to 3,130 feet, hematitic quartzite; 3,130 to 3,225 feet, glossy phyllitic marble ranging from gray to green to yellow; 3,270 to 3,400 feet, white granular recrystallized limestone with green schistose chlorite and sericite; 3,475 to 3,505 feet, white marble and glossy black phyllite. Goldstein (1955) called base of Cretaceous and top of Paleozoic at 3,150 feet; he said that the uppermost Paleozoic beds consist of dark gray limy shale, argillaceous limestone, and light green talcose phyllite (3,160 to 3,210 feet), they are succeeded by a series of pink altered limestones and green phyllites, and from 3,240 feet to total depth scattered samples are argillaceous limestones, limy argillites, and sandy limestones, all somewhat metamorphosed.

Petrographic study indicates a higher grade of metamorphism than that given in the above descriptions. The sample at 3,215 feet is a fine-grained garnetiferous sericite schist; at 3,485 feet the sample is composed of dolomitic sericite phyllite, dolomite marble, and very fine-grained dolomitic metaquartzite or metachert.

The discrepancy between Kleihege's base of Cretaceous (above) and determinations made by Sellards and Goldstein is very considerable; sample coverage now available for this well is very scanty, and the writer was not able to make an independent investigation. In view of the metamorphism seen in the lower part of the well, it is probable that it is located in the interior zone of the Ouachita belt and the upper unmetamorphosed part of the section is Cretaceous.

X-ray data.—None.

References.—Kleihege (1948, p. 48); Sellards (1933, p. 191).
Bureau of Economic Geology files.
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—Producers Oil Company No. 1 Bob Everett.

Location.—Section 40, block DB, CCSD&RGNG survey; 420 feet FEL, 2,400 feet FSL.

Elevation.—1,929 feet. *Total depth.*—2,530 feet. *Completed.*—1929.

Top of Paleozoic rocks.—1,365(?) feet. *Elevation of Paleozoic rocks.*— +564(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1530, 1575, 1760–65, 1990–2000.

Description of Paleozoic rocks.—Bureau of Economic Geology files report hard sandstone and hard black shale at 2,450 feet. Kleihege (1949) reported 400 feet of dark gray, fine-grained, poorly sorted, sandstone with a few thin-bedded layers of dark gray finely arenaceous shale below Cretaceous beds.

Thin section study shows a sequence of dark, fine-grained, angular, poorly sorted, slightly feldspathic dolomitic argillaceous quartz sandstone, locally containing bituminous material, and dark silty shale, locally carbonaceous. These are unmetamorphosed rocks, probably of Wolfcamp or Pennsylvanian age.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-day data.—I > Ch; 10/7 $\sim$ 3.5; F = 20; SR = 2.6.

References.—Kleihege (1948, p. 24).
Bureau of Economic Geology files.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—Reclamation Oil Producing Syndicate No. 1 J. B. Moore and Whitehead (also known as No. 1 McIntyre).

Location.—Section 491, CCSD&RGNG survey; 1,432 feet FNL, 714 feet FEL; 5 mi. due N of Del Rio.

Elevation.—1,050 feet. *Total depth.*—2,550 feet. *Completed.*—1923.

Top of metamorphic rocks.—2,400± feet. *Elevation of metamorphic rocks.*— -1,350± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2420–25. SHELL OIL COMPANY: 2370, 2420–35 (2), 2450.

Description of metamorphic rocks.—Descriptions in the Bureau of Economic Geology files report top of Paleozoic rocks at 2,170 feet; the sequence is described as gray sandy limestone, dolomite, calcareous sandstone, and limestone conglomerate; red beds are reported from 2,360 to 3,400 feet. Udden noted that the conglomerate from 2,360 to 2,400 feet does not resemble Permian or Pennsylvanian rocks.

Probably the determination of base of Cretaceous at 2,170 feet is in error and the entire section to 2,400± feet is Cretaceous. Samples below 2,400± feet are fine-grained metaquartzite and fine-grained dolomite marble(?); metamorphism is low grade with a high shearing component. Stretched grains show dimensional orientation.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1955. Samples are in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—Stanolind Oil and Gas Company No. 1 West.

Location.—Section 4, block C16, GC&SF survey; 1,620 feet FWL, 330 feet FSL.

Elevation.—1,883 feet, derrick floor. *Total depth.*—15,673 feet. *Completed.*—1956.

Top of Paleozoic rocks.—870 feet. *Elevation of Paleozoic rocks.*— +1,013 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Goldstein (1957) reported the following stratigraphic information: top of Strawn, 12,310 feet; top of Atoka, 12,440 feet; top of Devonian, 13,000 feet; top of Fusselman, 13,260 feet; top of Montoya, 13,380 feet; top of Simpson, 13,500 feet; top of Ellenburger, 14,121 feet. Montgomery (1958) noted top of Permian at 870 feet; total depth at 15,673 feet.

This well penetrated foreland basin rocks north of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1957; Porter Montgomery, Pan American Petroleum Corporation, 1958.

County.—Val Verde.

Well name.—Transcontinental Oil Company (Ohio) No. 1 W. S. Stephenson (Stevenson).

Location.—Section 8, block 4, I&GN survey; 300 feet FEL, 3,250 feet FSL; 4 mi. N of Del Rio.

Elevation.—1,065 feet. *Total depth.*—4,412 feet. *Completed.*—1927.

Top of metamorphic rocks.—2,423 feet. *Elevation of metamorphic rocks.*— -1,358 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 3815, 4050–4150, 4330. PAN AMERICAN PETROLEUM CORPORATION: 2406–08, 2450–55 (2), 2491–95, 2676–82, 2688–95, 2703–15, 2760–68, 2775–82, 2938–46, 2960–70, 2994–3002, 3106–12 (2), 3123–31, 3131–39, 3224–32 3262–70, 3328–33, 3338–43, 3373–78, 3845–50, 3950, 4050–4150. BUREAU OF ECONOMIC GEOLOGY: 2420–23, 2426–33 (2), 2455–60, 2472–75, 2521–25, 2532–38, 2592–98, 2670–82, 2675–82, 2702–09, 2715–22, 2729–35 (2), 2733–60, 2782–90, 2833–38 (2), 2846–54, 3232–40, 3317–23, 3390–96 (2), 3404–10 (2), 3500–08, 3596, 3605 (2), 3695–3725 (3), 3725–75, 4050–4150, 4340–45, 4348–83 (3), 4404–07 (3).

Description of metamorphic rocks—Kleihege (1949) placed base of Cretaceous at 2,408 feet and described the sequence as follows: 2,425 to 2,615 feet, metamorphosed shaly limestone grading downward into glossy slaty marble; 2,615 to 2,642 feet, white marble; 2,670 to 2,800 feet, partly recrystallized white, pink, and red limestone, locally sericitic; 2,800 to 2,855 feet, alternating white and red glossy marble; 2,855 to 2,890 feet, white and red partly recrystallized marble; 2,890 to 3,300 feet, white, gray, and red marble; 3,380 to 3,405 feet, glossy slaty crystalline limestone showing cataclastic structure; 3,485 to 3,575 feet, white crystalline limestone; 3,575 to 3,835 feet, slaty gray crystalline limestone containing olive-green phyllitic slate beds; 3,650 feet, unmetamorphosed limestone with stringers of slaty shale; 3,730 feet, partly recrystallized limestone showing cataclastic structures; 3,820 feet, slaty limestone; 3,835 to 4,150 feet, black fine-textured slaty shale containing a few white calcite veinlets; 4,160 to 4,415 feet, white marble.

Goldstein (1955) reported base of Cretaceous and top of Paleozoic at 2,430 feet.

Petrographic study shows that most of the rocks in the sequence are fine-grained (aphanitic) rudely foliated quartzose dolomitic calcite marble containing streaks and layers of graphitic and/or sericitic rock. Metamorphism is low grade with a very strong shearing element; foliation is expressed in dimensional orientation of stretched grains, oriented sericite fibers, and graphitic streaks.

This well penetrated metamorphic rocks in the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Kleihege (1948, p. 46).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Val Verde.

Well name.—D. Henry Werblow and Associates No. 1 Maude S. Newton.

Location.—Section 10, block 4, I&GN survey; 660 feet FNL, 660 feet FWL; 4 mi. NW of Del Rio.

Elevation.—1,126 feet. *Total depth.*—7,337 feet. *Completed.*—1955.

Top of metamorphic rocks.—2,660 feet. *Elevation of metamorphic rocks.*— -1,534 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2600–10, 2700–10, 2800–10, 2900–10, 3000–10, 3100–10, 3200–10, 3300–10, 3400–10, 3500–10, 3600–10, 3700–10, 3800–10, 3900–10, 4000–10, 4100–10, 4200–10, 4300–10, 4400–10, 4500–10, 4600–10, 4700–10, 4800–10 (2), 4900–10, 5000–10, 5100–10, 5200–10, 5300–10, 5400–10, 5500–10, 5600–10, 5700–10, 5800–10, 5900–10, 6000–10, 6100–10, 6200–10, 6290–00, 6390–00, 6490–00, 6590–00 (2), 6690–00, 6790–00, 6890–00, 7000–10, 7090–00, 7190–00, 7290–00, 7295–00.

Description of metamorphic rocks.—The pre-Cretaceous sequence in this well is composed of fine-grained calcite marble (grading into dolomitic calcite marble and dolomite marble toward the bottom of the well), fine-grained metaquartzite, and sericite phyllite; the major rock types grade into each other; for example, the metaquartzite is commonly calcareous and sericitic, the marble contains sericite, and the phyllite is calcareous and quartzose. Graphite and hematite are commonly present in streaks or layers or as finely disseminated particles; some of the marbles contain small amounts of albite. The metaquartzite is uniformly very fine-grained and originally may have been chert.

Metamorphism is low grade with a very high shearing element. Calcite marble is extensively twinned and the grains are stretched and deformed; metaquartzite grains are stretched; phyllite is excessively sheared and mica is "drawn out." Foliation is expressed in orientation of mica, stretched calcite, and quartz grains. The similarity of lithology over an interval of more than 4,500 feet suggests that the well may have penetrated steeply dipping beds; this is confirmed by the excessive hole deviation which occurred during drilling.

The sequence in this well has been called Ellenburger by some geologists (Stiles et al., 1955), probably because of the electric log characteristics of the dolomite marble section. The rocks are completely metamorphosed and are in no sense Ellenburger as the term is normally used.

The well penetrated metamorphic rocks in the interior zone of the Ouachita belt. The section is very similar to that penetrated in Transcontinental No. 1 Stephenson.

X-ray data.—I $>>$ K; 10/7 $\sim$ 12; F = 24?; SR = 6.4 (range from 4 to 12).

References.—Stiles et al. (1955).
Personal communication: J. R. Sandidge, Magnolia Petroleum Company, 1955; W. N. Tindell, Mayfair Minerals, Incorporated, 1955.

County.—Val Verde.

Well name.—Western Natural Gas No. 1 Bassett.

Location.—Section 5, block 195, TCRR survey; 660 feet FNL, 467 feet FEL.

Elevation.—1,883 feet. *Total depth.*—4,819 feet. *Completed.*—1953.

Top of Paleozoic rocks.—990 feet. *Elevation of Paleozoic rocks.*— +893 feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Reported as upper Paleozoic limestone and clastic rocks of foreland facies. This well is north of the Ouachita front.

X-ray data.—None.

References.—Personal communication: J. P. Olson, Shell Oil Company, 1959.

County.—Val Verde.

Well name.—E. T. Williams Drilling Company No. 1 W. T. O. Holman et al.

Location.—Section 5, block N, GH&SA survey; 200 feet FNL, 500 feet FWL; 10 mi. W and 11 mi. N of Del Rio.

Elevation.—1,293 feet. *Total depth.*—3,005 feet. *Completed.*—1921(?); 1927(?).

Top of metamorphic rocks.—2,110(?) feet. *Elevation of metamorphic rocks.*— -817(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3005.

Description of metamorphic rocks.—Sellards (1933) noted hard black shale and calcite. The driller's log in the Bureau of Economic Geology files reports metamorphism from 2,520 to 2,935 feet. The base of Cretaceous in this well is in doubt. Kleihege (1949) presented the following description: 2,110 to 2,115 feet, soft gray blocky shales and alternating beds of sandstone; 2,215 to 2,355 feet, mostly limestone; 2,350 to 2,410 feet, slightly indurated black shale; 2,600 feet, black slate containing traces of milky quartz and white calcite; 2,945 feet, black phyllitic slate with white calcite veinlets.

The single sample available for petrographic study is fine-grained graphitic quartzose dolomitic calcite marble. Metamorphism is low grade with a high shearing element; structures are twinning, grain stretching, and deformation.

At least the lower part of the well penetrated metamorphic rocks in the interior zone of the Ouachita belt. The section from 2,110 to 2,600 feet described by Kleihege is apparently unmetamorphosed, and its relation to the metamorphic rocks is not clear.

X-ray data.—None.

References.—Kleihege (1948, p. 42); Sellards (1933, p. 191).
Bureau of Economic Geology files.
Personal communication: E. A. Vogler, Shell Oil Company, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—Anderson No. 1 Teichelman.

Location.—A. Jett survey; 700 feet FNL, 150 feet FWL; 6 mi. N of Taylor.

Elevation.—622 feet. *Total depth.*—3,498 feet. *Completed.*—1938.

Top of Paleozoic rocks.—2,848 feet. *Elevation of Paleozoic rocks.*— −2,226 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3030–40, 3130–40, 3310–20, 3456–66, 3486–98.

Description of Paleozoic rocks.—Goldstein (1955) reported base of Travis Peak and top of Paleozoic (Pennsylvanian) at 2,848 feet; total depth 3,498 feet, in Pennsylvanian—Ouachita facies.

Petrographic study shows a sequence of dark dolomitic micaceous low-rank metasiltstone and sericite-chlorite clay-slate; the rocks are veined with quartz and bituminous material. Metamorphism is very weak; structures are incipient foliation and slaty cleavage.

This well penetrated incipiently to very weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Williamson.

Well name.—Burnette No. 1 D. C. Reed.

Location.—E. Leichtle League; 5,450 feet FSEL, 1,500 feet FSWL; 5 mi. SE of Bertram on County line.

Elevation.—1,158 feet. *Total depth.*—1,155 feet. *Completed.*—1939.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 860, 930, 1000 (2).

Description of Paleozoic rocks.—According to Goldstein (1955), this well was in Paleozoic rocks at 780 feet and the last sample at 1,040 feet was also in Paleozoic rocks; he interpreted the sequence as probably foreland facies.

The rocks are brown silty shale, olive-green shale veined with fine silica, argillaceous micaceous siltstone, and fine-grained, subangular to subround, poorly sorted, argillaceous calcareous quartz sandstone. The quartz appears to be mixed foreland and structural belt type.

This well is tentatively considered to have penetrated foreland rocks (probably Atoka beds) very close to or within the margin of the structural belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

County.—Williamson.

Well name.—S. L. Carpenter No. 1 S. J. Seward.

Location.—James Roebuck survey; 340 feet FSEL, 100 feet FNEL; 5½ mi. W of Schwertner.

Elevation.—893 feet. *Total depth.*—1,816(?), 2,023(?) feet. *Completed.*—1948.

Top of Paleozoic rocks.—1,630 feet. *Elevation of Paleozoic rocks.*— −737 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1670–80 (2), 1790–96, 1803–05 (2), 1888–90 (2), 1897–00 (2), 1908–12, 1920–22, 1935–38, 1966–68 (2), 2006–08 (2).

Description of Paleozoic rocks.—Goldstein (1958) from a study of the above suite of thin sections made the following tentative identifications: 1,670 to 1,796 feet, Stanley; 1,803 to 1,922 feet, Arkansas novaculite; 1,966 to 2,008 feet, Missouri Mountain and/or Blaylock formations.

The sequence penetrated in this well consists of (1) dark gray-green clay-slate, locally pyritic, commonly brecciated and deformed, and dark angular carbonaceous chloritic micaceous low-rank quartz metasiltstone, locally slightly dolomitic; (2) light to dark microgranular to cryptocrystalline to chalcedonic chert, sparsely dolomitic, locally with streaks and patches of dark organic material, locally containing scattered spicules, commonly brecciated, and dark spore-bearing siliceous shale containing dark organic matter; and (3) fine-grained, angular, low-rank quartz metasiltstone, locally pyritic, and dark deformed and brecciated chloritic and pyritic clay-slate. The rocks are cut by veinlets of quartz, carbonate, chlorite, and bituminous material. Metamorphism is very weak.

These rocks are Ouachita facies rocks of lower Paleozoic age, possibly overlain by very weakly metamorphosed Stanley beds. The well marks the easternmost occurrence of the pre-Stanley chert sequence in the central Texas area, and the cherts are associated with dark carbonaceous micaceous chloritic dolomitic metasiltstone and dark clay-slate similar to that found to the east in the belt of dark clastic rocks (Pl. 2). Possibly this well penetrated a transition zone and the dark clastic rocks are a nearer-source facies of the lower Paleozoic Ouachita facies known in outcrops.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Bell Oil and Gas Company, 1958; Porter Montgomery, Pan American Petroleum Corporation, 1957.

County.—Williamson.

Well name.—Carr (Hewitt and Dougherty) No. 1 Maggie Mather.

Location.—N. Campbell survey; 660 feet FSEL, 3,500 feet FNEL; 6 mi. N of Liberty Hill.

Elevation.—993 feet. *Total depth.*—7,545 feet. *Completed.*—1951.

Top of Paleozoic rocks.—780 feet. *Elevation of Paleozoic rocks.*—+213 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1100–10, 2316–17, 4880–90 (2), 6980–90 (2), 7530–40.

Description of Paleozoic rocks.—This well penetrated a sequence of dark shale, locally sandy and silty, and fine-grained, angular to subround, poorly sorted, argillaceous feldspathic quartz sandstone; the sandstones commonly contain abundant angular garnet in the heavy mineral fraction. Calcite veins are common; fine siliceous veinlets are present in some of the shales.

This sequence is Stanley shale. The well penetrated the frontal zone of the Ouachita structural belt near the northwestern margin.

X-ray data.—I > Ch > ML > K; 10/7 $\backsim$ 0.5; F = 20; SR = 1.65.

References.—Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—Donnelly et al. No. 2 Conway (also known as No. 1 Conway).

Location.—Burleson survey; 7 mi. SW of Liberty Hill (also given as Burleson League at Hopewell, 1 mi. E of Burnet County line, 7 mi. SW of Liberty Hill).

Elevation.—950 feet (from topographic map). *Total depth.*—1,133 feet. *Completed.*—Before 1930.

Top of Paleozoic rocks.—695 feet. *Elevation of Paleozoic rocks.*—+255 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 695, 720, 730, 740, 750, 760, 770, 780, 790, 800, 810, 820, 830, 840, 850, 867, 880, 890 (3), 900, 920 (2), 930, 940, 950, 970 (2), 980, 962–1000 (3), 990, 1000 (2), 1010 (3), 1020, 1030 (2), 1040, 1050, 1060, 1070 (2), 1080.

Description of Paleozoic rocks.—Sellards (1931b) reported siliceous limestone and black shale and quoted Miser as having identified the rocks as Bigfork chert. Goldstein (1955) noted Paleozoic rocks of probable Ouachita facies from 700 to 1,080 feet (last sample); he remarked that the sediments differ from Ouachita Mountain lithology, but they are brecciated and veined with quartz.

Petrographic study shows fine-grained calcareous argillaceous silty dolomite and dolomitic limestone with lesser amounts of dolomitic chert and glauconitic spiculitic limestone; beds of sandy and silty shale, and fine-grained, angular to subround, fairly well-sorted, argillaceous slightly feldspathic quartz sandstone are more common toward the bottom of the section. Quartz and calcite veinlets are common; garnet is present in the heavy mineral suite of the sandstone.

This sequence seems to have no counterpart either in foreland rocks or in Ouachita facies beds within the structural belt. The presence of extensive veining and the deformed and brecciated condition of some of the rocks indicate that the sequence is probably within the structural belt. The well is located near other wells interpreted to have penetrated foreland basin rocks close to or within the margin of the structural belt. If Miser is correct in his identification of Bigfork, it is probable that there is frontal thrusting in this area; the writer believes that these rocks are of foreland or transitional facies, possibly Atoka or older.

X-ray data.—None.

References.—Sellards (1930a, p. 83; 1931b, p. 827).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

***County.*—Williamson.**

Well name.—Georgetown City Water Well.

Location.—City of Georgetown Tract; near I&GN depot.

Elevation.—750± feet. *Total depth.*—1,820 feet. *Completed.*—1914.

Top of Paleozoic rocks.—1,260± feet. *Elevation of Paleozoic rocks.*— -510± feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1700, 1820 (3).

Description of Paleozoic rocks.—Udden (1919) discussed this well and made a number of observations: 1,280 feet, red shale or slate cut by quartz veins; 1,340 feet, dark gray indurated micaceous slaty shale; between 1,300 and 1,800 feet, black schistose shale. Udden remarked that six samples taken between 1,280 and 1,820 feet are highly fissured material bordering between schist and shale, slickensided, and cut by quartz veins; he concluded that the rocks are Precambrian. Sellards (1931b) described the rock as schistose shale.

Two samples studied are chloritic micaceous low-rank metasiltstone, slaty, low-rank to high-rank metasandstone, and silty metashale; the rocks are invaded by quartz-chlorite-dolomite veins. The variability of metamorphism (ranging from incipient to weak) suggests that the rocks have been locally altered by metasomatic-hydrothermal effects of the vein-forming solutions.

This well penetrated dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 ⌒ 5; F = 20; SR = 4.2.

References.—Sellards (1930a, p. 86; 1931b, p. 823); Udden (1919, pp. 125–126).
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—W. E. Green (Reeves) No. 1 Lehman.

Location.—Elisha Davis survey; 1½ mi. N of Jarrell.

Elevation.—786 feet. *Total depth.*—3,064 feet. *Completed.*—1950.

Top of Paleozoic rocks.—1,350±(?) feet. *Elevation of Paleozoic rocks.*— -564±(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1450–60, 1650–60, 2050–60, 2470–80, 2680–90, 2750–60, 2980–90 (2).

Description of Paleozoic rocks.—The Paleozoic sequence is composed of fine-grained, mostly angular to subround, poorly sorted, micaceous-chloritic-argillaceous feldspathic quartz sandstone containing abundant angular garnet in the heavy mineral fraction (Stanley lithology) overlying a sequence of dark gray-green, pyritic, variably siliceous sporadically radiolarian-bearing shale, and dark argillaceous chert and siliceous shale rich in dark organic matter, commonly veined with quartz, calcite, and/or bituminous material (pre-Stanley Ouachita facies, probably Arkansas novaculite or Bigfork). There is no metamorphism; structures are fracturing, brecciation, and veining.

This well penetrated Stanley and pre-Stanley Ouachita facies rocks in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—Lois Henna et al. No. 1 (2?) Alsabrook (Alsterbrook?).

Location.—D. Curry survey; 2 mi. N of Round Rock.

Elevation.—759 feet. *Total depth.*—2,333 feet. *Completed.*—1948.

Top of Paleozoic rocks.—1,520 feet. *Elevation of Paleozoic rocks.*— -761 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1790–1800, 2300–2330, depth unknown (2).

Description of Paleozoic rocks.—H. J. Plummer (Bur. Econ. Geol. files) reported dark fissile shale and black finely crystalline limestone—Marble Falls(?). The samples examined are very dark carbonaceous silty metashale and clay-slate veined by quartz and quartz-bitumen. Metamorphism is incipient to very weak.

This well penetrated incipiently to very weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Bureau of Economic Geology files.
Personal communication: Porter Montgomery, Pan American Petroleum Corporation, 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—Hewitt and Dougherty No. 1 Pearson.

Location.—W. H. McGill survey; 1,400 feet F most S'ly SEL, 1,980 feet FSWL; 5 mi. N of Liberty Hill.

Elevation.—1,087 feet. *Total depth.*—9,104 feet. Completed.—1954(?).

Top of Paleozoic rocks.—855 feet. *Elevation of Paleozoic rocks.*—+232 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 970–80 (2), 1170–80 (2), 2500–10, 4100–10 (2), 5900–10 (2), 8200–10.

Description of Paleozoic rocks.—The sequence is composed of dark, fine-grained, subangular to subround, poorly sorted, argillaceous feldspathic quartz sandstone, locally calcareous and locally containing angular garnet, and dark gray locally sandy and silty shale. The shales are brecciated.

The sandstones show some resemblance to Stanley sandstones, but they are locally calcareous and appear to be better rounded. The sequence is either Stanley or Atoka.

The well is within the northwest boundary of the structural belt.

X-ray data.—I > Ch > ML > K; 10/7 ~ 1.6; F = 20; SR = 2.1. Presence of kaolinite suggests Atoka.

References.—Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—W. M. Jarrell No. 1 C. N. Avery, Jr.

Location.—E. Ryan survey; 2 mi. E of Hutto.

Elevation.—646 feet. *Total depth.*—2,953 feet. *Completed.*—1950.

Top of Paleozoic rocks.—2,680 feet. *Elevation of Paleozoic rocks.*— -2,034 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2700–10, 2800–10, 2900–10 (2).

Description of Paleozoic rocks.—The pre-Cretaceous sequence is composed of dark, fine-grained, angular, dolomite carbonaceous micaceous chloritic quartz metasiltstone (mostly low rank) and black carbonaceous or graphitic metashale or clay-slate; the rocks are veined with quartz-chlorite. Metamorphism ranges from incipient to weak; shales show incipient foliation, but there is no strong shearing element.

This well penetrated incipiently to weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—I > Ch; 10/7 ~ 0.7; F = 20.

References.—Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—Sol Kopel No. 1 Ragsdale (Sauer).

Location.—T. W. Medcalf survey; 6½ mi. NE of Liberty Hill.

Elevation.—960 feet, derrick floor; 959 feet, ground. *Total depth.*—1,620 feet. *Completed.*—1951.

In Paleozoic rocks at 850 feet. *Elevation of Paleozoic rocks.*— > +110 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 850–65, 928–86, 998–1004, 1049–53, 1126–35, 1200–06.

Description of Paleozoic rocks.—The Paleozoic sequence in this well is composed of dark locally pyritic siliceous(?) shale or metashale containing dark organic material and extensively veined with quartz, calcite, and bituminous material (less commonly veined with chlorite), overlying fine-grained, mostly angular, poorly sorted, argillaceous micaceous feldspathic quartz sandstone which locally contains angular garnet in the heavy mineral fraction and which also is veined by quartz and calcite. Metamorphism ranges from none to incipient; shales show local brecciation.

The first two samples (above) are altered (sericitized and chloritized) olivine gabbro similar to Balcones Cretaceous-Tertiary intrusive igneous rocks; possibly these gabbroic rocks are emplaced in the overlying Cretaceous section but possibly they also intrude Paleozoic rocks in this well. There may be local contact metamorphism.

The upper dark siliceous(?) shale section is probably part of the Stanley; the sandstones below are typical Stanley. This well penetrated Stanley shale in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Porter Montgomery, Pan American Petroleum Corporation. 1957.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—R. C. Miller and R. V. Mayfield No. 1 Miller (Fee).

Location.—Malone survey; 3 mi. E of Liberty Hill.

Elevation.—1,000 feet (from topographic map). *Total depth.*—1,910 feet. *Completed.*—1926.

Top of Paleozoic rocks.—858 feet. *Elevation of Paleozoic rocks.*—+142 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 867–72, 908–16, 967–1000, 1830 (3), depth unknown (5).

Description of Paleozoic rocks.—Sellards (1931b) reported top of Paleozoic black shale at 696± feet and concluded that it is probably Stanley-Jackfork. Barnes (*in* Sellards, 1933) noted that "metamorphism is very slight" and said that the rock is "little more than a shale." Goldstein (1955) reported top of Paleozoic at 858 feet and identified the rocks as Pennsylvanian—Ouachita facies(?).

Petrographic study shows that the sequence is composed of dark sandy and silty shale, micaceous feldspathic siltstone, and fine-grained, mostly angular, poorly sorted, argillaceous, micaceous, and chloritic feldspathic quartz sandstone; profuse veinlets of quartz, calcite, and bituminous material transect the rocks, and plant fragments are abundant. Locally the presence of new chlorite indicates incipient metamorphism. Most of the quartz and feldspar grains are very angular, but there are occasional round grains (foreland source?). Garnet and authigenic tourmaline are present in the heavy mineral fraction of the sandstones. The sequence is Stanley shale.

This well penetrated the frontal zone of the Ouachita belt.

X-ray data.—I > Ch > ML; 10/7 ⌢ 0.6; F = 20. The sample from 1,830 feet shows a small amount of mixed-layer illite-montmorillonite, which indicates foreland tendencies.

References.—Sellards (1931b, pp. 823, 826; 1933, p. 135).
Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—Palm Valley Oil Company (Round Rock Oil Company?) No. 1 Walsh.

Location.—Dillard survey; 5½ mi. W of Round Rock.

Elevation.—839 feet (by aneroid barometer). *Total depth.*—1,230 feet. *Completed.*—1915.

Top of Paleozoic rocks.—1,230± feet. *Elevation of Paleozoic rocks.*— -391± feet.

Thin section coverage (depth in feet).—None.

Description of Paleozoic rocks.—Sellards (1931b) described the Paleozoic rock as "novaculite." The location of this well and rocks penetrated in nearby wells suggest that it penetrated incipiently to very weakly metamorphosed dark clastic rocks, but Sellards' lithologic description indicates that it encountered pre-Stanley rocks of Ouachita facies (Pl. 2). No samples or other published or unpublished descriptions are available. Possibly the situation is similar to that in No. 1 Seward to the northeast (p. 332) which may have penetrated a transitional zone between siliceous rocks and dark clastic rocks.

X-ray data.—None.

References.—Sellards (1931b, p. 823; 1933, p. 192).

County.—Williamson.

Well name.—Orville H. Parker (Parker Petroleum Company, Incorporated) No. 1-A Pearson.

Location.—J. Shelton survey; 4½ mi. W of Round Rock.

Elevation.—900± feet. *Total depth.*—6,510 feet. *Completed.*—1956.

Top of Paleozoic rocks.—1,430 feet. *Elevation of Paleozoic rocks.*— -530 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 1440–50, 1450–60 (2), 2090–3000 (3), 3000–10 (3), 3170, 3650–60 (3), 4090–4100 (3), 4565–75 (3), 5990–6000 (3), 6490–6500 (2).

Description of Paleozoic rocks.—The sequence is composed of: (1) dark, locally silty, metashale or clay-slate which in some intervals is pyritic and/or dolomitic; contortion and brecciation are common and quartz veins are abundant; (2) fine-grained pyritic micaceous low-rank metasiltstone veined with quartz, commonly sandy; and (3) fine-grained, angular, poorly sorted, silty micaceous feldspathic quartz low-rank metasandstone (locally graywacke) veined with quartz; rock fragments, mostly phyllite and metaquartzite, are abundant in some intervals. Dark fine-grained pyritic dolomite occurs in the 4,090 to 4,100-foot interval. Metamorphism is incipient to very weak; structures are incipient foliation, brecciation, and contortion.

This well penetrated incipiently to very weakly metamorphosed dark clastic rocks in the interior part of the frontal zone of the Ouachita belt.

X-ray data.—$I > Ch$; $10/7 \sim 1.8$; $F = 20$; $SR = 2.6$. Shales are composed of well-crystallized illite-chlorite of Ouachita type.

References.—Personal communication: M. W. Eddleman, Parker Petroleum Company, Incorporated, 1956; A. P. Werner, 1956.

County.—Williamson.

Well name.—Jesse Russell No. 1 A. B. McGill.

Location.—T. F. Gray survey; 4,445 feet FEL, 6,775 feet FSL.

Elevation.—1,118 feet, derrick floor. *Total depth.*—4,331 feet. *Completed.*—ni.

Top of Paleozoic rocks.—695 feet. *Elevation of Paleozoic rocks.*— +423 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 713–20 (2), 828–35, 1238–44, 1406–15, 1816–25 (2), 2431–40, 2440–45, 2651–60, 3500–10, 4300–05.

Description of Paleozoic rocks.—Goldstein (1955) reported first sample in Pennsylvanian at 1,472 feet; top of Smithwick, 2,400(?) feet; total depth 4,331 feet, in Smithwick.

The sequence is composed of dark silty shale, argillaceous micaceous siltstone, and fine- to coarse-grained, mostly fairly well-sorted, slightly argillaceous and micaceous calcareous to dolomitic quartz sandstone, locally slightly feldspathic; rock fragments (chert, shale, siltstone, stretched quartz mosaic, and phyllite) are present in the sandstones in some intervals. There is no metamorphism. The sequence is Atoka.

This well penetrated foreland rocks close to and possibly within the margin of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: August Goldstein, Jr., Pan American Petroleum Corporation, 1955.

Samples are in Bureau of Economic Geology Well Sample Library.

County.—Williamson.

Well name.—Shell Oil Company (and Sinclair Oil and Gas Company) No. 1 Purcell.

Location.—W. H. McGill survey; 1,196 feet FWL of McGill survey, 1,196 feet FSL of Purcell Tract; 18 mi. NW of Georgetown.

Elevation.—1,074 feet, derrick floor; 1,060 feet, ground. *Total depth.*—9,485 feet. *Completed.*—1954.

Top of Paleozoic rocks.—720 feet. *Elevation of Paleozoic rocks.*— +354 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 820–30, 1320–30, 2050–60 (2), 2380–90, 3300–10, 5500–10, 6320–30, 6490–00, 6530–40, 6760–70 (2), 6920–30, 9387–97. SHELL OIL COMPANY: 8237, 9389–90, 9396–97, 9475–79 (2).

Description of Paleozoic rocks.—The following stratigraphic data are reported for this well: top of Atoka, 720 feet; top of Marble Falls—Barnett, 6,900± feet; top of Ellenburger (Honeycut), 6,940 feet; top of Gorman, 7,775 feet; top of Tanyard, 8,290 feet; top of glauconite-bearing rocks, 8,810 feet; top of San Saba, 8,960 feet; top of Point Peak, 9,380 feet; top of Morgan Creek, 9,400 feet; top of granite gneiss, 9,470 feet. Identifications from top of Ellenburger to total depth are by Barnes (1956), who noted that the Ordovician beds are normal foreland shelf facies. The Precambrian granite gneiss in this well resembles the Town Mountain granite of the Llano uplift area; this well is the farthest southeast penetration of the Precambrian basement of the Texas craton (Flawn, 1956).

The Atoka sequence is dark silty shale, locally micaceous, and/or carbonaceous, and fine-grained mostly subangular, poorly to fairly well-sorted, slightly argillaceous to slightly calcareous quartz

sandstone, locally slightly feldspathic. There is no metamorphism. Marble Falls—Barnett rocks are dark calcareous shales containing abundant siliceous and calcareous spicules.
This well penetrated foreland rocks close to or within the margin of the Ouachita belt.

X-ray data.—I > Ch > ML > K(?); 10/7 ~ 1.0; F = 20; SR = 1.9.

References.—Barnes (1959, p. 674); Flawn (1956, pp. 30, 202–203).
Personal communication: V. E. Barnes, Bureau of Economic Geology, 1956; R. P. Maner, Shell Oil Company, 1958.
Samples are in Bureau of Economic Geology Well Sample Library.

County.—Wilson.

Well name.—Quintana Petroleum Corporation No. 1-A A. L. Moore.

Location.—D. O. Warren League; 1,100 feet FNWL, 1,200 feet FSWL; 4 mi. SW of Dewville.

Elevation.—432 feet. *Total depth.*—9,177 feet. *Completed.*—1945.

Top of metamorphic rocks.—9,168 feet. *Elevation of metamorphic rocks.*— -8,736 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 7172–76, 9168–72.

Description of metamorphic rocks.—The samples are hematitic chlorite-sericite phyllite and phyllitic metaquartzite containing small garnet crystals and larger octahedral non-magnetic porphyroblasts of brookite(?), octahedrite(?); quartz veins are common. Metamorphism is low to medium grade; foliation is well developed.
This well penetrated metamorphic rocks in the interior zone of the Ouachita belt. It provides the southernmost control point for mapping.

X-ray data.—None.

References.—Goldstein and Reno (1952, p. 2289).

County.—Zavala.

Well name.—Park and Phillips No. 1 Flowers and Ward Ranch.

Location.—Section 20, block 1, I&GN survey; 660 feet FNL, 1,980 feet FEL; 16 mi. SW of Uvalde.

Elevation.—826 feet. *Total depth.*—7,290 feet. *Completed.*—1955.

Top of metamorphic rocks.—7,240 feet. *Elevation of metamorphic rocks.*— -6,414 feet.

Thin section coverage (depth in feet).—SHELL OIL COMPANY: 7256.

Description of metamorphic rocks.—The single sample examined is very fine-grained amphibole-epidote schist. Metamorphism is low grade with a high shearing element; structures are foliation and microfaulting. The original rock may have been a basaltic igneous rock.
This well penetrated metamorphic rocks in the interior zone of the Ouachita belt and is one of the southernmost control points for mapping.

X-ray data.—None.

References.—Bureau of Economic Geology files.

PART 2. SUMMARY REPORTS ON SELECTED WELLS PENETRATING ROCKS OF THE OUACHITA BELT AND ADJACENT FORELAND IN OKLAHOMA AND MEXICO

AUGUST GOLDSTEIN, JR., AND PETER T. FLAWN

Information on the following wells was compiled from many different sources. The bulk of the basic well data and stratigraphic data are from files of operating companies and State or Federal agencies. The petrographic data are original; all petrographic determinations made on samples from Oklahoma wells are by August Goldstein, Jr. X-ray determinations were made by C. E. Weaver.

The symbol *ni* means that no information was available.

OKLAHOMA

County.—Bryan.

Well name.—Atlantic Refining Company No. 1 Brown.

Location.—Section 16, township 8S, range 8E; NW/4, NW/4, SE/4.

Elevation.—661 feet. *Total depth.*—6,676 feet. *Completed.*—1950.

Top of Paleozoic rocks.—1,590 feet. *Elevation of Paleozoic rocks.*— -929 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 1600, 1610, 1735, 1815, 2055, 2272-77, 2294-2300, 2345, 2595, 2870, 2915, 3195, 3235, 3345, 3575, 3655, 3745, 4095, 4155, 4165, 4195, 4215, 4275, 4305, 4485, 4692, 4745, 4785, 4850, 4880, 4995, 5045, 5145, 5200, 5375, 5470, 5635, 5710, 5825.

Description of Paleozoic rocks.—Top of Stanley was encountered at 1,590 feet and the well bottomed in Stanley at 6,676 feet. The sequence is composed of (1) fine-grained, angular to round (mostly angular), poorly to very poorly sorted, argillaceous chloritic micaceous feldspathic quartz sandstone (and siltstone), commonly containing fragments of chert and quartz mosaic, locally calcareous, carbonaceous, or siliceous, locally containing abundant detrital garnet; the feldspar includes both plagioclase and potassium feldspar; (2) dark silty shale and metashale (locally clay-slate), locally chloritic, calcareous, carbonaceous, and pyritic; (3) between the intervals 3,195 and 4,215 feet, the samples contain fragments of fine-grained argillaceous tuff, partly to completely devitrified, locally chloritic; and (4) locally the sequence contains carbonate rock, fine-grained pelletiferous limestone in the interval 2,294 to 2,300 feet, and glauconitic silty limestone and cone-in-cone carbonate in the interval 5,145 feet. Dark bituminous graptolitic chert and dolomitic spiculitic chert in the interval 5,635 feet may be caved material. Stanley sandstones appear to be unusually calcareous in this area. Locally the rocks show incipient to very weak metamorphism.

This well penetrated Stanley beds in the frontal zone of the Ouachita belt southwest of the buried Arbuckle element.

X-ray data.—None.

References.—None.

County.—Bryan.

Well name.—Atlantic Refining Company No. 1 State.

Location.—Section 36, township 7S, range 8E; SE/4, SW/4, SW/4.

Elevation.—664 feet. *Total depth.*—6,647 feet. *Completed.*—1945.

Top of Paleozoic rocks.—1,570 feet. *Elevation of Paleozoic rocks.*— -906 feet.

Thin section coverage (depth in feet).—PAN AMERICAN PETROLEUM CORPORATION: 1720, 1724, 1727, 1730, 1978, 2218, 2298, 2330, 2390, 2660, 2700, 2721, 2890, 2926, 3040, 3240, 3422, 3727, 3790, 3910, 4180, 4455, 4700, 4825, 4830. 4835, 4855, 4865, 4870, 4875, 4885, 4920, 5020-30, 5045, 5055, 5075, 5190-5200, 5196, 5200-10, 5210-20, 5220-30, 5230-40, 5240-50, 5270-80, 5280-90, 5290-5300, 5300, 5360-70, 5390, 5740.

Description of Paleozoic rocks.—The stratigraphic sequence encountered in this well is: base of Cretaceous and top of Stanley, 1,507 feet; top of Arkansas novaculite, 4,740 feet; top of Polk Creek, 5,160 feet; top of Bigfork, 5,175 feet; top of Womble, 5,680 feet; total depth, 6,647 feet in Womble.

The Stanley is composed of (1) dark silty shale and metashale, locally micaceous, chloritic, carbonaceous, siliceous, and pyritic and (2) fine-grained angular to subround, poorly sorted, argillaceous chloritic micaceous feldspathic quartz sandstone (and siltstone) commonly containing abundant fragments of chert and quartz mosaic, locally calcareous, pyritic. The Stanley appears to be unusually calcareous in this area; both potassium feldspar and plagioclase are present. Calcite and bitumen veinlets transect the rock. The Arkansas novaculite is composed of light and dark cryptocrystalline to microgranular chert and siliceous shale, commonly containing radiolarians and spicules, locally silty, dolomitic, pyritic, and with abundant organic material. Veinlets of bitumen are common. Possibly Missouri Mountain beds are present at the base of the sequence. The Polk Creek is black carbonaceous shale which grades downward into the siliceous shale and chert of the Bigfork. Bigfork rocks are (1) dark cryptocrystalline to microgranular chert and siliceous shale, commonly containing radiolarians, spicules, and graptolite fragments, commonly calcareous and dolomitic, pyritic, argillaceous, and rich in organic material; (2) dark argillaceous siliceous dolomitic limestone, commonly containing spicules, graptolites, locally bituminous, glauconitic, or pyritic. Veinlets of carbonate and bituminous material are common. The underlying Womble is composed of dark pyritic bituminous chloritic shale or metashale containing graptolites and conodonts.

Locally the rocks show incipient to very weak metamorphism.

This well penetrated a normal Ouachita facies sequence in the frontal zone of the Ouachita belt southwest of the buried Arbuckle element.

X-ray data.—None.

References.—None.

County.—Bryan.

Well name.—Carter Oil Company No. 1 Jewel Loyd.

Location.—Section 21, township 7S, range 10E; C, NW/4; 8 mi. SE Durant.

Elevation.—664 feet, derrick floor. *Total depth.*—7,023 feet. *Completed.*—1959.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks.*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 2180–87, 2600–10, 3010–20, 3430–40, 3510–20, 3600–10, 3649, 3750–60, 3900–10, 3940–50, 3990–4000, 4040–50, 4190–4200, 4300–10, 4750–60, 4800–10, 5100–10, 5350–60, 5370–80, 5520–30, 5570–80, 5650–60, 5680–90, 6000–10, 6200–10, 6750–60, 6900–10.

Description of Paleozoic rocks.—The following stratigraphic information is reported: top of Ouachita facies, 3,395 feet; top of Arkansas novaculite, 3,428 feet; top of Missouri Mountain, 3,876 feet; top of Polk Creek, 3,940 feet; top of Bigfork, 3,976 feet; top of Womble, 4,772 feet; thrust fault and top of Arkansas novaculite, 5,190 feet; top of Missouri Mountain, 5,468 feet; top of Polk Creek, 5,556 feet; top of Bigfork, 5,590 feet; top of Womble, 6,038 feet; total depth, 7,023 feet, in Womble.

Petrographic study shows the following lithologic units (from top to bottom): (1) very fine-grained, subangular, poorly sorted, argillaceous feldspathic quartz sandstone (graywacke) containing fragments of chert and metamorphic rocks and dark silty shale; this unit includes thin sections 2180–87 to 3010–20 and indicates that the well penetrated Ouachita facies rocks considerably higher than the "top of Ouachita facies" reported above; lithology is typical Stanley; (2) microgranular to cryptocrystalline chert, locally pyritic, bituminous, dolomitic, spiculitic, and radiolarian-bearing, commonly cut by veinlets of quartz-bitumen and calcite, and dark spiculitic siliceous shale or argillaceous chert; this unit includes thin sections 3430–40 to 3750–60; lithology is typical of the Arkansas novaculite; (3) the thin section from 3649 feet is fine-grained, sharply angular, very poorly sorted, argillaceous feldspathic quartz sandstone (graywacke) containing large grains of feldspar and fragments of granite; the matrix appears to be tuffaceous; this sample is probably caved material from overlying Stanley beds; (4) red (hematitic) and green (pyritic) silty clay-slate; the single thin section is from the interval 3900–10; the rock is identified as Missouri Mountain; (5) pyritic bituminous argillaceous dolomitic limestone (marlstone); the single thin section is from the interval 3940–50—from general stratigraphic position the rock is probably Polk Creek but it contains much more carbonate than exposed Polk Creek rocks; (6) this unit includes thin sections 3990–4000 to 4800–10 and is composed of pyritic bituminous calcareous dolomitic cryptocrystalline to microgranular chert containing spicules, graptolite debris, and fragments of ostracod carapaces, dark bituminuous, pyritic, calcareous shale or metashale containing spores, radiolarians, graptolites, and spicules, locally pyritized, and fossiliferous limestone, locally siliceous, bituminous, pyritic, commonly containing spicules, ostracods, and graptolites; calcite and quartz-bitumen veinlets are common, and calcite in veinlets is commonly twinned; these rocks are Bigfork; (7) a thrust or reverse fault occurs between the 4800–10- and 5100–10-foot intervals—the 5100–10 sample is fine-grained, subangular, very poorly sorted, quartz sandstone and dark shale or metashale; the lithology is characteristic of upper Paleozoic rocks (Stanley?) rather than Womble, as was reported; (8) thin sections below 5100–10, including intervals 5350–60 to 6200–10, show a repetition of the above sequence and include Arkansas novaculite, Missouri Mountain, Polk Creek, and Bigfork lithologies; (9) thin sections from the 6750–60 and 6900–10 intervals are fine-grained, fairly well-sorted, quartz sandstone and coarse siltstone, locally micaceous, and dark metashale or clay-slate; the heavy mineral suite is largely zircon, tourmaline, and leucoxene and indicates a pre-Missouri Mountain age—these rocks are probably Womble.

Most of the rocks are unmetamorphosed but locally there is incipient to very weak metamorphism. The siliceous rocks are commonly fractured. Veins are most common in pre-Stanley rocks and include quartz-bitumen and calcite veins.

The well penetrated a sequence of Ouachita facies rocks repeated by faulting in the frontal zone of the Ouachita belt immediately southwest of the buried Arbuckle element.

X-ray data.—None.

References.—Scout report on formation tops.

County.—Marshall.

Well name.—Capitol Hill Oil Company No. 1 Williams.

Location.—Section 20, township 6S, range 6E; SW/4, SW/4, NW/4.

Elevation.—775 feet. *Total depth.*—7,013 feet. *Completed.*—1953.

Top of Paleozoic rocks.—840 feet. *Elevation of Paleozoic rocks.*— -65 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 960–70 (2), 1400–10, 1950–60, 1980–90, 2000–10 (2), 2120–30, 2200–10, 2290–2300, 2370–80, 2440–50, 2450–60, 2490–2500, 2530–50, 2550–60, 2620–40, 2640–60, 2670–80, 2730–50, 2790–2810, 2820–30 (2), 2830–40 (2), 2850–55, 2855–60 (2), 2880–90 (3), 2915–20, 3590–95, 3630–35, 3650–85, 3725–30, 3750–55, 3900–05, 3915–20, 4340–50, 4840–90, 5070–80, 5090–5100, 5140–50, 5150–60 (2), 5170–80, 5230–40, 5240–70, 5340–50 (3), 5360–70, 5400–20, 5470–5510, 5550–60, 5600–10, 5750–60, 6390–6410, 6800–10, 7010–13.

Description of Paleozoic rocks.—According to the log of Mr. Clement A. Weintz, this well penetrated a section of gray, finely micaceous to glassy very fine-grained sandstone and dark gray shale from about 1,095 to 2,380 feet. From 2,810 to 2,895 feet, there is a zone of dark brown chert and siliceous shale with abundant brown spores. From 2,895 to 3,000 feet, there is a zone of variable lithology, dominated by blue-green to olive-green smooth shale and argillaceous dolomite. This material passes gradationally into waxy and flaky green to dark green shale with occasional brown streaks and a few sand grains. This shale zone extends from 3,000 to 3,585 feet. At 3,585 feet the well penetrated a zone of sooty black slickensided shale underlain by dark brown brittle hard siliceous shale. This zone extends to approximately 3,750 feet. From 3,750 to 3,990 feet there are alternations of brown shale and green smooth flaky shale with a thin zone of dark brown chert at 3,900 to 3,920 feet. The well was diamond-cored from 3,990 to 4,335 feet and no samples are available. At 4,335 feet there is some dark brown siliceous shale which grades into green splintery to waxy shale with graptolites. This zone extends from 4,335 to 4,840 feet. From 4,840 to about 5,040 feet, there is another zone of dark brown siliceous shale and chert. Underlying this zone and extending to 5,205 feet is a group of sediments of variable lithologic character, including light-colored cherts, dolomite, green shale, and siltstone. From 5,205 to 5,335 feet, the rocks consist of dark brown siliceous shale and chert. From 5,335 to 5,575 feet, the rocks are predominantly light-colored mottled cherts, dolomitic at places. This zone passes gradationally into dark brown siliceous shale and chert from 5,575 to 5,700 feet. From 5,700 feet to total depth of 7,013 feet, the well penetrated green to dark green waxy shales with a few sandy streaks and graptolite debris.

Petrographic data are summarized as follows:

The Atoka(?) formation was encountered immediately beneath the Cretaceous and extends to 2,810 feet. It may be divided into two members or zones in this well: (1) an upper zone of tight, micaceous, very fine-grained sandstone, siltstone, and gray shale and (2) a lower zone of dark gray shale and siliceous shale. The sandstones and shales of the upper zone are apparently unmetamorphosed and cannot be positively identified as of either "normal" facies or "frontal zone Ouachita" facies. The spiculitic siliceous shales with abundant pyrite in the lower zone are similar to siliceous shales in the Stanley-Jackfork-Atoka sequence of the Ouachita Mountains. Insofar as known to the writer, this unusual lithologic type has not been reported from Pennsylvanian sediments of the Arbuckle Mountains.

No rocks which are lithogenetic equivalents of the Wapanucka-Chickachoc (Morrow) horizon or Mississippian Caney are present in this well unless they are represented by argillaceous sediments in the lower part of the Atoka(?) from 2,380 to 2,810 feet.

Outcrop samples of both the Bigfork and Woodford-Arkansas novaculite horizons contain dark brown, sapropelic, pyritic cherts which are lithologically similar. However, abundant graptolite debris is widespread in and typical of the Bigfork chert (Ordovician) at Black Knob Ridge. It has not been found in thin sections of rocks from the Woodford-Arkansas novaculite horizon (Devonian-Mississippian). On the other hand, thin sections of the latter typically contain well-preserved spores and radiolarians. The Bigfork chert contains some radiolarians and some questionable spores, but the preservation and general appearance of the fossils is markedly different from that in the younger formations. Consequently, it is considered practicable to separate the similar cherts and siliceous shales on the basis of their microflora and microfauna, even though generic and specific identifications cannot be made. This approach was followed herein.

The chert and siliceous shale zone from 2,810 to 2,895 feet contains abundant spores and radiolarians. It contains no graptolites and more closely resembles Woodford than Arkansas novaculite on the basis of lithology. The light-colored argillaceous chert and siliceous shale at 2,880 feet may represent the lithogenetic equivalent of the Pinetop chert horizon.

The zone of mixed lithology from 2,895 to 3,000 feet cannot be correlated at this time, but it probably contains equivalents of some or all of the Hunton group and Sylvan of the Arbuckle Mountains or the Missouri Mountain and Polk Creek of the Ouachita Mountains.

The waxy to flaky green shale zone from 3,000 to 3,585 feet more closely resembles sediments of the Womble rather than Simpson in general lithology.

No identifiable microfossils were found in the siliceous shale zone from 3,585 to 3,750 feet. The peculiar "yellow bodies" observable in thin sections at this depth are also found in the Woodford, but this may not be significant. This zone is tentatively termed Woodford(?) on the basis of lithologic appearance alone.

At 3,900 to 3,920 feet some of the cherts contain fragmentary graptolites, and it is probable that the well is in Ordovician(?) sediments at that depth. Below the diamond cores there are graptolites in the green shales. The general appearance of this section also suggests that the rocks are closely allied to the Womble sediments.

The chert and siliceous shale zone from 4,840 to 5,040 feet contains Woodford-type spores and radiolarians and are referred to that formation.

The mixed group of sediments from 5,040 to 5,205 feet contains probable Silurian and Upper Ordovician sediments tentatively referred to the Hunton-Sylvan and Missouri Mountain—Polk Creek.

The siliceous shale and chert zone from 5,205 to 5,335 feet contains fragmentary graptolites. It is the lithogenetic equivalent of the Upper Bigfork at Black Knob Ridge.

The chert, dolomitic chert, and siliceous dolomite zone from 5,335 to 5,575 feet is probably equivalent to the lower part of the Bigfork at Black Knob Ridge.

The green shale section from 5,700 to 7,013 feet more closely resembles Womble than Simpson.

Capitol Hill Oil Company No. 1 Williams was drilled in a faulted area in which slices of sedimentary rock are piled upon one another in varying thickness and at various angles of dip. The most nearly complete sedimentary sequence is that from 4,840 feet to total depth of 7,013 feet in which the various formations from Woodford (Devonian-Mississippian) to Womble (Ordovician) are apparently present in normal sequence and in more or less normal thickness.

The lithology and petrographic character of these rocks from this well are neither strictly of normal facies nor strictly of Ouachita facies. It must be presumed that the sediments encountered were laid down in the frontal zone of the Ouachita Mountains distal to the axis of the downwarping, between the geosyncline and the foreland. In the Black Knob Ridge area it may be that sedimentary rocks equivalent to those in Capitol Hill No. 1 Williams are in the faulted zone between the Ti Valley and Choctaw faults, although those rocks which are older than Middle Devonian do not crop out.

X-ray data.—None.

References.—None.

County.—Marshall.

Well name.—Gulf Oil Corporation No. 1 Berniece (also known as No. 1 NPFP).

Location.—Section 25, township 5S, range 5E; NW/4, NE/4, NE/4, North Madill pool.

Elevation.—758 feet, derrick floor. *Total depth.*—7,250 feet. *Completed.*—1957.

Top of Paleozoic rocks.—ni. *Elevation of Paleozoic rocks*—ni.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 3900–10, 4150–60, 4600–10, 4800–10, 4990–5000, 5050–60, 5100–10, 5300–10, 5425–30, 5460–65, 5700–05, 5760–65, 5950–60, 6500–05, 6550–60, 6775–80, 6900–05, 7000–05, 7245–50.

Description of Paleozoic rocks.—The following stratigraphic information is reported: top of Springer or Goddard, 3,140 feet; top of Caney, 4,660 feet; top of Sycamore, 4,890 feet; top of Woodford, 5,050 feet; top of Hunton detrital, 5,425 feet; top of Sylvan, 5,444 feet; top of Viola, 5,739 feet; top of Bromide, 6,400 feet; top of Tulip Creek, 6,770 feet; top of McLish, 7,125 feet.

Petrographically, the upper part of the sequence is pyritic carbonaceous micaceous chloritic silty shale, locally calcareous, bituminous, and siliceous, and pyritic argillaceous bituminous silty limestone, locally glauconitic and fossiliferous. Beneath the shale and limestone section are typical Woodford rocks, including red-brown pyritic bituminous calcareous spore-bearing siliceous shale and chert. The Woodford rests on a lower Paleozoic foreland sequence of fossiliferous argillaceous bituminous clastic limestone, limy shale, pyritic bituminous shale and silty shale, and fine- to medium-grained, rounded, well-sorted calcareous quartz sandstone, locally quartzitic.

This well penetrated foreland rocks west of the Ouachita structural belt.

X-ray data.—None.

References.—Personal communication: W. R. Johnson, The Texas Company, 1958.

County.—Marshall.

Well name.—Magnolia Petroleum Company No. 1 Beard.

Location.—Section 7, township 7S, range 6E; SE/4, SE/4, NW/4.

Elevation.—635 feet. *Total depth.*—2,010 feet. *Completed.*—ni.

Top of Paleozoic rocks.—740 feet. *Elevation of Paleozoic rocks.*— −105 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 730–40, 1000–1100, 1320–30, 1410–15, 1750–60, 2000–10.

Description of Paleozoic rocks.—The following stratigraphic data are reported: base of Trinity, 740 feet; top of unweathered Stanley, 880 feet; total depth, 2,010 feet, in Stanley

The sequence is composed of (1) fine-grained, subangular to subround, poorly sorted, argillaceous feldspathic quartz sandstone (graywacke) containing detrital mica, abundant rock fragments, and with a "mud" matrix partly reconstituted into new chlorite and sericite and (2) dark silty and sandy metashale or clay-slate, locally siliceous, bituminous, and pyritic. Metamorphism is very weak.

This well penetrated the Stanley shale in a disturbed zone close to the western margin of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: J. Eric Bucher, Magnolia Petroleum Company, 1959.

County.—Marshall.

Well name.—Shell Oil Company No. 1 Keystone.

Location.—Section 10, township 8S, range 5E; SE/4, SW/4, NW/4.

Elevation.—654 feet, derrick floor. *Total depth.*—10,043 feet. *Completed.*—1957.

Top of Paleozoic rocks.—663 feet. *Elevation of Paleozoic rocks.*— −9 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 750–60, 950–60, 2350–60, 2800–10, 3250–60, 8785–90, 8850–55, 9050–55, 9300–05.

Description of Paleozoic rocks.—This well is reported to have encountered Pennsylvanian (Morrow) rocks at 633 feet and bottomed in Pennsylvanian (Morrow) beds at 10,043 feet.

The main rock types are (1) silty and sandy clastic limestone (calcarenite), locally fossiliferous, containing fine- to medium-grained, subangular to subround quartz sand, chert, glauconite, phosphatic material, bituminous material, and clay; fossil fragments include spicules, ostracods, bryozoans, crinoids, and foraminifers of *Millerella* type; (2) fine-grained, subangular to subround, well-sorted, calcareous quartz sandstone containing detrital calcite, chert, glauconite, fossil fragments, and phosphatic material with a calcareous, and less commonly argillaceous-micaceous or siliceous, matrix. Locally there are fine-grained compact limestones without appreciable sand or silt, some of which are pelletiferous and some of which are composed largely of fossil fragments. Sandstones and limestones grade into each other with limestone generally more abundant, particularly toward the bottom of the well.

This well penetrated foreland facies Pennsylvanian rocks of Morrow age west of the Ouachita belt; the abnormal thickness of the sequence indicates faulting or folding.

X-ray data.—None.

References.—Personal communication: Carl Branson, Oklahoma Geological Survey, 1958.

County.—Pittsburg.

Well name.—Southwest Exploration Company No. 1 Hoehman.

Location.—Section 16, township 2N, range 14E; SE/4, NE/4, SE/4.

Elevation.—775 feet. *Total depth.*—8,758 feet. *Completed.*—1954.

Top of Paleozoic rocks.[43] *Elevation of Paleozoic rocks.*— +775 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 80–90, 750–60, 1440–50, 2500–10, 3480–90, 3500–10, 5450–60, 6800–10, 8650–60, 8730–40.

Description of Paleozoic rocks.—The sequence is composed of (1) dark micaceous silty shale or metashale, locally carbonaceous or containing dark red-brown organic material; (2) fine- to medium-grained, mostly subangular, fairly well-sorted to poorly sorted, calcareous quartz sandstone; (3) coarse-grained, subangular, fairly well-sorted, carbonaceous micaceous quartz siltstone, and fine-grained quartz sandstone, locally argillaceous or siliceous; and (4) fine-grained, subangular, well-sorted, calcareous to siliceous quartz sandstone. The sandstones contain minor feldspar and rock fragments and detrital mica.

The entire sequence is Atoka. The well is located in the frontal part of the Ouachita Mountains, between the Pine Mountain and Ti Valley faults.

[43] Well was spudded in Atoka.

X-ray data.—None.

References.—None.

County.—Pushmataha.

Well name.—Erle Halliburton No. 1 Bagwell.

Location.—Section 30, township 3S, range 15E; SW/4, SW/4, NE/4, NE/4.

Elevation.—585 feet. *Total depth.*—6,010 feet. *Completed.*—ni.

Top of Paleozoic rocks.—900±(?) feet. *Elevation of Paleozoic rocks.*— -315±(?) feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 930–35, 1150–55, 1250–55, 1500–10, 2150–60, 2900–10, 3690–3700, 4250–60, 4350–60, 4400–10, 5150–60, 5990–6000.

Description of Paleozoic rocks.—This well penetrated a sequence of Stanley shale under a thin Cretaceous cover and bottomed in Stanley.

The sequence is composed of (1) fine- to medium-grained, subangular to subround, poorly sorted, argillaceous feldspathic quartz sandstone (graywacke), locally micaceous, chloritic, pyritic, commonly containing abundant rock fragments, and with a partly reconstituted "mud" matrix; (2) angular siliceous and calcareous micaceous quartz siltstone; and (3) dark chloritic micaceous metashale or clay-slate, locally pyritic and bituminous. Argillaceous sandy tuff and dark siliceous shale containing spicules and radiolarians occur in the 5,990 to 6,000-foot interval. The rocks are veined by quartz and calcite; metamorphism is incipient to very weak.

This sequence is typical of the Stanley formation in the frontal zone of the Ouachita belt.

X-ray data.—None.

References.—None.

County.—Pushmataha.

Well name.—Southwest Exploration Company No. 1 Denton Perrin.

Location.—Section 9, township 2S, range 15E; C, SE/4, SW/4.

Elevation.—562 feet, kelly bushing. *Total depth.*—11,328 feet. *Completed.*—ni.

Top of Paleozoic rocks.[44] *Elevation of Paleozoic rocks.*— +562 feet.

Thin section coverage (depth in feet).—BUREAU OF ECONOMIC GEOLOGY: 100–120, 600–605, 980–985, 1250–55, 1995–2000, 3500–05, 4000–05, 6300–05, 6545–50, 6690–6700, 6900–05, 6980–85, 7075–80, 7300–05, 7500–05, 7600–05, 7850–55, 8050–55, 8600–05, 9095–9100, 9500–05, 9700–05 (2), 9985–90, 10,022–24, 10,150–55, 10,972–11,000.

Description of Paleozoic rocks.—Two interpretations of the stratigraphic sequence encountered are as follows:

(1) Spudded in Stanley; Hatton tuff zone in Stanley, 5,047 to 5,080 feet; Arkansas novaculite, 6,460 feet; Missouri Mountain shale, 6,956 feet; Polk Creek shale, 7,066 feet; Bigfork chert, 7,456 feet; fault and Stanley, 9,020 feet; Hatton tuff zone in Stanley, 9,984 to 10,020 feet; Arkansas novaculite, 10,972 feet.

(2) Spudded in Stanley; upper Hatton tuff, 5,044 feet; lower Hatton tuff, 5,312 feet; Arkansas novaculite, 6,490 feet; Missouri Mountain shale, 6,955 feet; Polk Creek shale, 7,155 feet; Bigfork chert, 7,465 feet; Womble shale, 9,014 feet; reverse fault and Mississippian(?), 10,770 feet; total depth, 11,328 feet, in varicolored chert.

The thin sections studied fall into five groups. Group 1, including sections 100–120 through 4000–05, is composed of fine-grained, subangular to subround, poorly sorted, argillaceous feldspathic quartz sandstone containing abundant chert and shale fragments, argillaceous quartz siltstone, and dark silty shale or metashale, locally pyritic, carbonaceous, or bituminous; these rocks are Stanley. Group 2, including sections 6300–05 through 6900–05, is mostly chert and siliceous shale. The chert ranges from dark red-brown pyritic bituminous dolomitic cryptocrystalline to microgranular chert containing spores and radiolarians to light-colored spiculitic chert, locally chalcedonic; quartz, carbonate, and bitumen veinlets are common. The sequence includes dark dolomitic shale or metashale and dark bituminous siliceous shale. This interval includes the Arkansas novaculite and possibly older beds as well. Group 3, including sections 6980–85 through 7300–05, is made up of dark pyritic bituminous calcareous and dolomitic silty shale and metashale and fine-grained siltstone, locally containing radiolarian remains; this sequence was not identified but is lithologically similar to the lower Paleozoic Ouachita facies. Group 4, including sections 7500–05 through 8600–05, is composed of dark red-brown pyritic bituminous dolomitic spiculitic chert and fragmental fossiliferous bituminous clastic limestone, in part dolomitic and siliceous; fossils include spicules, ostracods, pelmatozoan fragments, and graptolitic(?) debris. Quartz, carbonate, and bitumen veinlets are common. These rocks are Bigfork. Group 5, including sections 9095–9100 through 10,150–55, is made up mostly of sandstone and shale. In the upper part are dark bituminous calcareous silty shale and fine-grained, sub-

[44] Well was spudded in Stanley.

angular to subround, poorly sorted, calcareous quartz sandstone with abundant fragments of chert, shale, quartzite, phyllite, limestone, and mica; below, chloritic calcareous tuff occurs in the sandstone-shale sequence. The tuff is typical of the Hatton tuff lentil of the Stanley, so that the sandstone-shale sequence above is probably Stanley. The single section below Group 5 (10,972–11,000 interval) is a siliceous shale, possibly from the top of the Arkansas novaculite.

This well penetrated a typical and fairly complete sequence of Ouachita facies in the frontal zone of the Ouachita belt sequence. The sequence is repeated by faulting. The petrographic data support stratigraphic interpretation (1).

X-ray data.—None.

References.—Personal communication: G. H. Thompson, Shell Oil Company, 1958.

MEXICO

Estado.—Coahuila.

Well name.—Peyotes No. 2-A.

Location.—Approximately 82.5 km. S 22° W from Eagle Pass, Texas.

Elevation.—692.3 meters. *Total depth.*—1,812 meters. *Completed.*—1956.

Top of metamorphic rocks.—1,761 meters. *Elevation of metamorphic rocks.*— –1,068.7 meters.

Thin section coverage (depth in meters).—BUREAU OF ECONOMIC GEOLOGY: 1762.8–65.0, 1786.1–86.7, 1810.3–12.0.

Description of metamorphic rocks.—Goldstein (1958) described a core fragment from the 1762.8 to 1765.0-meter interval as a very fine-grained micaceous metaquartzite showing stretched quartz grains; he compared the rock to those found in the interior zone of the Ouachita structural belt in Caldwell County, Texas. Masson (Díaz G., 1958) called samples from 1,786 and 1,810 meters quartz schist and quartz mica schist, respectively; he noted the presence of biotite as well as muscovite and referred the rock to the biotite zone of regional metamorphism.

Rocks studied are fine-grained muscovite-albite-quartz schist and fine-grained sericitic to muscovitic feldspathic metaquartzite. Metamorphism is low grade with a strong shearing component—structures are foliation, crush zones, and sharp microfolding. A trace of very pale biotite occurs within masses of sericite, but the amount is very small and appears to have no great significance as far as grade of metamorphism is concerned.

On the basis of location, lithology, and type of metamorphism it is probable that this well penetrated the interior zone of the Ouachita belt.

X-ray data.—None.

References.—Personal communication: Teodoro Díaz G., Petroleos Mexicanos, 1958; August Goldstein, Jr., Bell Oil and Gas Company, 1958.

Estado.—Nuevo Leon.

Well name.—Chapa No. 101.

Location.—11,750 meters S 77°09′ E of the town of Cerralvo.

Elevation.—189 meters, kelly bushing. *Total depth.*—3,280 meters. *Completed.*—1958.

Top of metamorphic rocks.—3,182(?) meters. *Elevation of metamorphic rocks.*— –2,993(?) meters.

Thin section coverage (depth in meters).—BUREAU OF ECONOMIC GEOLOGY: 3188.3–3192.8, 3192.8–3199.3 (9).

Description of metamorphic rocks.—The sequence is composed of dark gray-green sericite-chlorite slate, locally carbonaceous, commonly containing abundant leucoxene, and dark green, fine- to medium-grained, angular, poorly sorted, chloritic micaceous feldspathic high-rank quartz metasandstone, locally dolomitic, carbonaceous, pyritic, and locally containing abundant rock fragments (slate-phyllite, chert, quartz mosaic). Some samples are metagraywackes. Foliation is well developed, and locally the slates show incipient fracture cleavage; in the metasandstones new sericite is commonly oriented at a high angle to original bedding as indicated by plates of second-cycle mica-chlorite. Metamorphism is weak—quartz and feldspar have not recrystallized but reconstitution of mica-chlorite appears to be complete. The general lithology is of orogenic facies.

This well is located far from other wells that penetrate pre-Mesozoic rocks. The lithology and type of metamorphism are similar to those which occur in the interior zone of the Ouachita belt in the black slate belt of Travis, Bastrop, and Hays counties, Texas.

X-ray data.—None.

References.—Personal communication: D. C. Buzzo, Edwin W. Pauley, Northeast Mexico Division, 1958; Teodoro Díaz G., Petroleos Mexicanos, 1959.

PART 3. SUMMARY REPORTS ON SELECTED WELLS PENETRATING PALEOZOIC ROCKS IN THE SOUTHEASTERN STATES

PHILIP B. KING

The following list gives significant data on Triassic(?), Paleozoic, and older rocks in selected wells in the southeastern states. These data indicate the basis for the features shown on the geologic map (Pl. 3) and for interpretations made in the text. The list includes only records of wells in critical areas, mainly toward the south; for records of wells farther north, see publications in the bibliography. In critical areas most wells which are known to have entered Paleozoic or older rocks are listed, although for some of them little information is available as to the nature of the rocks penetrated. Wells are grouped according to the subcrop map units in which they occur. Publications referred to are given in the bibliography. Citations based on unpublished communications are italicized. Some informants have requested that their names be withheld, so that some of the data given are not documented.

UNIT PENETRATED

TRIASSIC(?)

(1)[45] *Nelson Exploration Company No. 1 Smith Lumber Company*
Alabama, Crenshaw County; Sec. 26, T. 8 N., R. 16 E.
Elev. 396 ft.; T. D. 10,830 ft.; completed 1948.
Triassic(?) rocks.—Red micaceous shale and other red clastic rocks from 3,156 feet to total depth, of which 4,285 feet have been assigned to the Triassic(?) (McKee and others, 1959). According to Applin, some geologists have suggested a Paleozoic age for the lower part of the red clastic rocks. Higher red strata probably include equivalents of Jurassic (Cotton Valley) and Lower Cretaceous.
References.—Applin, 1951, p. 28, table 5, well 90; McKee and others, 1959, pl. 4.

(2) *W. B. Hinton No. 1 J. S. Creel*
Alabama, Barbour County; Sec. 14, T. 9 N., R. 26 E.
Elev. 504 ft.; T. D. 5,546 ft.; completed 1939.
Triassic(?) rocks.—According to driller's log, from 3,000 feet to total depth penetrated dark red shales and sandstones of Early Cretaceous age or older; overlain by Tuscaloosa formation. Of these, 1,085 feet have been ascribed to the Triassic(?). At 5,342 to 5,372 and 5,491 to 5,522 feet they contain diabase sills or dikes.
References.—Bowles, 1941, pp. 252–256; Applin, 1951, p. 26, table 4, well 79; McKee and others, 1959, pl. 4.

(3) *H. A. Stebinger No. 1 Alice S. Robertson*
Alabama, Barbour County; Sec. 19, T. 10 N., R. 26 E.
Elev. 554 ft.; T. D. 5,215 ft.; completed 1939.
Triassic(?) rocks.—According to driller's log, penetrated shale, sandy shale, and sand, mostly red, below 4,135 feet. Diabase dikes or sills at 4,135 to 4,152, 4,202 to 4,208, and 4,273 to 4,274 feet.
References.—Bowles, 1941, pp. 256–260; Applin, 1951, p. 26, table 4, well 80.

(4) *Messergill & Williams (R. G. Hauser) No. 1 T. R. Grubles*
Alabama, Barbour County; Sec. 9, T. 11 N., R. 26 E.
Elev. 649 ft.; T. D. 3,384 ft.; completed 1948.
Triassic(?) rocks.—Sample of bottom hole core at 3,378 feet reported by Charles Milton to be "probably Triassic" (*P. L. Applin, 1960*).

(5) *Robert York Trustee No. 1 S. V. Dismuke*
Alabama, Barbour County; Sec. 16, T. 12 N., R. 27 E.
Elev. 272 ft.; T. D. 2,727 ft.; completed 1948.
Triassic(?) rocks.—Core at total depth and a little above reported by Charles Milton to "resemble Triassic sediments" (*P. L. Applin, 1960*).

(6) *Renwar Oil Corporation No. 1 H. D. Granberry*
Alabama, Henry County; Sec. 6, T. 4 N., R. 29 E.
Elev. 193 ft.; T. D. 6,610 ft.; completed 1956.

[45] These numbers refer also to well numbers on Plate 3.

Triassic(?) rocks.—Top at 5,980 feet. Core at 6,326 feet is of Triassic(?) aspect. Top of Paleozoic is reported at 6,528 feet from electric log. Samples are currently being studied by E. R. Applin. (*P. L. Applin, 1960*).

(7) *Sowega Minerals Exploration Company No. 1 J. W. West*
Georgia, Calhoun County; Lot 328, Land Dist. 4.
Elev. 345 ft.; T. D. 5,265 ft.; completed 1950.
Triassic(?) rocks.—Penetrated 1,340 feet of Triassic(?) rocks; diabase from 5,190 feet to total depth. Overlain by Lower Cretaceous(?).
References.—Applin, 1951, p. 26, table 4, well 85; McKee and others, 1959, pl. 4.

(8) *Stanolind Oil & Gas Company No. 1 J. H. Pullen*
Georgia, Mitchell County; Lot 133, Land Dist. 10.
Elev. 338 ft.; T. D. 7,487 ft.; completed 1944.
Triassic(?) rocks.—At 7,350 to 7,470 feet, diabase sills or dikes in clastic rocks of Triassic(?) age; other igneous rocks at 6,550 to 6,620 and 7,070 to 7,090 feet.
Reference.—Applin, 1951, p. 27, table 4, well 87.

(9) *Pan-American Petroleum Corporation No. 1 J. R. Sealy*
Florida, Walton County; Sec. 9, T. 1 S., R. 18 W.
Elev. 99 ft.; T. D. 11,947 ft.; completed 1958.
Triassic(?) rocks.—Rocks of Early Cretaceous age were penetrated at about 5,060 feet, but in the unfossiliferous clastic rocks below this depth Lower Cretaceous and older stratigraphic units have not been clearly differentiated. Red shale and red sand are major constituents of the cuttings beginning at about 7,650 feet and probably are at least in part of Triassic(?) age. Igneous rock occurs in cuttings from 11,910 feet to total depth (*P. L. Applin, 1960*).

(10) *Humble Oil & Refining Company No. 1 G. H. Hughes*
Florida, Taylor County; Sec. 12, T. 5 S., R. 6 E.
Elev. 36 ft.; T. D. 6,254 ft.; completed 1948.
Triassic(?) rocks.—Clastic rocks at about 5,960 to 6,153 feet, overlying basaltic rock at 6,153 to 6,165 feet, and diabase gabbro at 6,165 to 6,254 feet.
References.—Applin, 1951, p. 26, table 4, well 83; 1957, p. 1489, table 4, well 21.

(11) *Gulf Oil Corporation No. 1 Brooks-Scanlon Inc., Block 33*
Florida, Taylor County; Sec. 18, T. 4 S., R. 9 E.
Elev. 96 ft.; T. D. 5,243 ft.; completed 1950.
Triassic(?) rocks.—Clastic rocks of Triassic(?) age at about 5,140 feet, underlain from 5,200 feet to total depth by diabase gabbro.
Reference.—Applin, 1951, p. 26, table 4, well 81.

Besides the wells listed, other wells in the same parts of Alabama, Georgia, and Florida drilled through Triassic(?) rocks into Paleozoic or older rocks. See wells 57, 58, 62, 63, 64, 65, and 80, listed below.

Permian(?)

Representative wells which have been drilled into the Eagle Mills formation of Permian(?) age in southern Arkansas prior to 1945 are listed by Hazzard and others (1947, p. 485). No further compilation of well data on this formation has been made by the writer.

Pennsylvanian

(12) *Lion Oil Company No. 1 Nally*
Arkansas, White County, Sec. 33, T. 8 N., R. 7 W.
Elev. 425 ft.; T. D. 6,397 ft.; completed 1945.
Paleozoic rocks.—Published log (Maher and Lantz, 1953) shows Atoka formation at surface; Morrow group at 890 feet; Jackfork sandstone at 1,510 feet; Stanley shale at 2,570 feet; underlain by Penters chert(?) (Devonian) at 5,545 feet, and by Ordovician formations, with Everton formation at total depth.
The well is near the edge of the Mississippi embayment, in the Arkansas basin about 30 miles north of the structural front of the Ouachita Mountains. Well log correlation indicates that the units assigned to the Stanley and Jackfork thin westward across the Arkansas basin, the first changing into the Mississippian formations of the Ozark Mountains sequence, and the second wedging out entirely.
References.—Maher and Lantz, 1953, well 10; Caplan, 1954, pp. 15–17; Sheldon, 1954, pp. 199–204.

(13) *W. W. Martin & J. H. Coker No. 1 W. H. Stewart*
Arkansas, Prairie County, Sec. 3, T. 3 N., R. 5 W.
Elev. 210 ft.; T. D. 3,163 ft.; completed 1946.
Paleozoic rocks.—Top at 1,878 feet. Driller's log shows alternating thin units of sand, sandy shale, shale, black shale, and lime. These rocks are probably Atoka formation, which crops out about 25 miles along the strike to the west.
Overlain by basal sand of Upper Cretaceous.
Reference.—Renfroe, 1949, pp. 128–129.

(14) *Panhandle Eastern Pipeline Company No. 1-22 Ives*
Arkansas, Prairie County; Sec. 22, T. 1 S., R. 4 W.
Elev. 207 ft.; T. D. 11,950 ft.; completed 1958.
Paleozoic rocks.—Top at 3,303 feet. Sample log shows a monotonous sequence of shale and sandstone to total depth. Some of the shales are micaceous, others lustrous, others black; most of the sandstone is fine grained. Samples contain vein quartz fragments and pyrite. The well lies outside the Ouachita structural front as projected, but the nature of the samples suggests deformation and weak metamorphism. Probably much or all of the sequence is Atoka formation.
Overlain by basal sand of Upper Cretaceous.
Reference.—Sample log from *Arkansas Geological and Conservation Commission, 1960.*

(15) *David J. Flesh No. 1 Rosencrantz et al.*
Arkansas, Arkansas County; Sec. 2, T. 3 S., R. 6 W.
Elev. 219 ft.; T. D. 3,635 ft.; completed 1947.
Paleozoic rocks.—Top at 3,464 feet. Driller's log records very hard shale, brittle splintery shale, hard quartzitic sand, and lime to total depth. Sidewall cores at 3,470 and 3,518 feet are hard, tightly cemented, dense, micaceous quartzite, the second core pyritic; sidewall core at 3,583 feet is hard black shale with some quartzite and micaceous material. Assigned to Atoka formation in log; well is close to Ouachita structural front as projected, and the record suggests deformation and weak metamorphism.
Overlain by pre-Nacatoch sand of Upper Cretaceous.
Reference.—Renfroe, 1949, pp. 17–18.

(16) *Ryan Consolidated Petroleum Corporation No. 1 Roy McCollum*
Arkansas, Arkansas County; Sec. 24, T. 2 S., R. 5 W.
Elev. 215 ft.; T. D. 3,731 ft.; completed 1947.
Paleozoic rocks.—Top at 3,530 feet. Driller's log records "hard shale flint and novaculite at top: bottom of hole in Atoka."
Overlain by sand correlated with Ozan formation (Upper Cretaceous).
References.—Renfroe, 1949, pp. 18–19; Caplan, 1954, pl. 5, well 5.

(17) *Blackwell Oil & Gas Company (C. W. Robinson) No. 1 E. P. Fox*
Arkansas, Arkansas County; Sec. 23, T. 5 S., R. 3 W.
Elev. 190 ft.; T. D. 4,372 ft.; completed 1941.
Paleozoic rocks.—Top at 4,337 feet. Driller's log records alternating shale and chert; the "chert" may actually be novaculite or very fine-grained quartzitic sandstone. "The Fox well is assumed to have been abandoned in the Atoka since the presence of chert or novaculite has not been determined with assurance" (Caplan, 1954). The well is close to the Ouachita structural front as projected.
Overlain by sand correlated with Ozan formation (Upper Cretaceous).
Reference.—Caplan, 1954, p. 13; pl. 5, well 6; pl. 8, well 7.

(18) *Continental Oil Company No. 1 DeWitt Bank & Trust Company*
Arkansas, Arkansas County; Sec. 32, T. 5 S., R. 2 W.
Elev. 186 ft.; T. D. 4,520 ft.; completed 1954.
Paleozoic rocks.—Top at 4,500(?) feet. Cuttings are black, pyritic, blocky shale; chert fragments (*W. M. Caplan, 1960*). Correlation of these rocks is uncertain; the well is close to the Ouachita structural front as projected.
Overlain by basal sand of Upper Cretaceous.

(19) *J. L. Youngblood No. 1 J. B. West*
Arkansas, Arkansas County; Sec. 24, T. 4 S., R. 2 W.
Elev. 183 ft.; T. D. 4,183 ft.; completed 1949.
Paleozoic rocks.—Top at 4,160(?) feet. Driller's log records dark gray to black quartzitic sandstone, assigned to Atoka formation; circulation sample at total depth described as black, very fine-grained quartzitic sandstone or novaculite, black brittle shale, and black micaceous shale. Caplan (1954) interpreted the former as novaculite but suggested it forms detrital fragments in the Atoka formation.
Overlain by Ozan(?) formation (Upper Cretaceous).
Reference.—Caplan, 1954, pp. 13–14; well 6, pl. 8.

(20) *Plymouth Oil Company No. 1 Bush*
Arkansas, Phillips County; Sec. 2, T. 6 S., R. 1 E.
Elev. 155 ft.; T. D. 4,595 ft.; completed 1956.

Paleozoic rocks.—Top at 4,575 feet. Sidewall cores at 4,583 feet are reported to be gray limy shale (*W. M. Caplan, 1960*).

Overlain by Ozan formation or older Upper Cretaceous.

(21) *McAlester Fuel Company & H. M. Cox No. 1 E. M. Welch*
Arkansas, Phillips County; Sec. 24, T. 4 S., R. 2 E.
Elev. 174 ft.; T. D. 4,939 ft.; completed 1948.

Paleozoic rocks.—Top at 4,522 feet. Driller's log records "anhydrite and lime" from 4,522 feet to total depth; sidewall cores at 4,700 and 4,891 feet are "bituminous coal." The anhydrite and lime of the driller's log are inexplicable if the rock is Paleozoic, but the coal of the sidewall cores is compatible with Atoka formation.

Overlain by Ozan formation or older Upper Cretaceous.

Reference.—Renfroe, 1949, pp. 101–103.

(22) *McAlester Fuel Company No. A-1 Home Lumber Company*
Arkansas, Phillips County; Sec. 27, T. 3 S., R. 2 E.
Elev. 171 ft.; T. D. 4,576 ft.; completed 1948.

Paleozoic rocks.—Top at 4,461(?) feet. Consists of quartzitic sandstone and dark gray to black shale. Sidewall core at 4,523 feet reported to be dark brown lignitic shale. "Top of Paleozoic may be at base of the green shale" (*W. M. Caplan, 1960*). Rocks below green shale suggest Atoka formation.

Overlain by Upper Cretaceous(?).

(23) *Union Producing Company No. 1-A Tensas Delta*
Louisiana, Morehouse Parish; Sec. 8, T. 22 N., R. 4 E.
Elev. 71 ft.; T. D. 10,475 ft.; completed 1940.

Paleozoic rocks.—Top at 9,285 feet. The Paleozoic rocks, termed the Morehouse formation, have been penetrated to a thickness of 1,190 feet. They are mainly gray, brownish-gray, and black shales and siltstones, with minor gray sandy shales, gray sandy limestones, and red shales. The shales are carbonaceous, siliceous, or finely micaceous, and are less commonly dolomitic or calcareous. Some beds contain carbonized or pyritized plant remains. There is no apparent dip in the cores, and the rocks are not metamorphosed.

Cores at various levels contain a sponge, a scaphopod, 9 genera of pelecypods, and the bellerophontid gastropod *Patellostium*. The pelecypods resemble those in Pennsylvanian and Permian faunas elsewhere, and the gastropod resembles Pennsylvanian species (Imlay and Williams, 1952). A core at 10,243 to 10,253 feet contains plant spores of the genera *Illinites*, *Florinites*, and *Puncti-sporites* which indicate a Middle or Late Pennsylvanian age (Hoffmeister and Staplin, 1954).

Overlain unconformably by Werner formation and Louann salt (Hazzard and others, 1947), of Jurassic(?) age.

The structure and history of the Paleozoic rocks in this famous well have been much discussed, but no final interpretations are possible, as rocks like these have not been reached by drilling in surrounding areas. The Paleozoic rocks might be earlier than the Ouachita orogeny but have escaped deformation because they were on the axis of a fold, or in a stable mass that resisted deformation (Imlay and Williams, 1942), or they may have been deposited after the orogeny (H. J. Morgan, 1952). They are not in contact with the Eagle Mills formation, penetrated in wells to the north, but they are generally believed to be older (McKee and others, 1956); however, it has been suggested that they might be younger (Hazzard and others, 1947).

References.—Imlay, 1940a, pp. 7–8; Imlay and Williams, 1942, pp. 1672–1673; Hazzard and others, 1947, p. 486; H. J. Morgan, 1952, pp. 2269–2271; Hoffmeister and Staplin, 1954, pp. 158–159; McKee and others, 1956, p. 1.

(24) *Phillips Petroleum Company No. 1 Knowlton & Perthshire*
Mississippi, Bolivar County; Sec. 2, T. 24 N., R. 7 W.
Elev. 164 ft.; T. D. 6,009 ft.; completed 1937.

Paleozoic rocks.—Top at 4,700(?) feet. Reported to be shale and limy shale, probably equivalent to the Atoka formation. "A core fragment from 5,677 to 5,683 feet is sheared, silty and sandy, bituminous, pyritic dolomite; black opaque bituminous material occurs in irregular streaks and fracture fillings. The rock is more characteristic of the foreland facies than of the Ouachita facies. It is not metamorphosed, but it is sheared and fractured, suggesting proximity to the Ouachita belt" (*P. T. Flawn, 1959*).

Overlain by pre-Tokio strata (Lower Cretaceous).

Reference.—Caplan, 1954, pl. 5, well 8; Beikman and Drakoulis, 1958a, p. 14.

The following additional wells in Bolivar County are reported to have been drilled into the Paleozoic, but no information is available as to the nature of the rocks penetrated (Beikman and Drakoulis, 1958a, p. 14): Central Oil Company No. 1 Tuminello; Hunt Oil Company No. 1 Raymer. See also well 70 (p. 358).

(25) *Roeser & Pendleton No. 1 Young & Ogilvie*
Mississippi, Tallahatchie County; Sec. 32, T. 25 N., R. 2 E.
Elev. 160 ft.; T. D. 3,970 ft.; completed 1940.
Paleozoic rocks.—Top at 3,750 feet. Reported to have entered igneous rock and altered shale. Rocks are of "Ouachita" facies (*H. J. Morgan, Jr., 1958*). As this well is considerably north of the Ouachita structural front as projected, the rocks penetrated are here interpreted as being Pennsylvanian, altered either by deformation or igneous intrusion.
Overlain by Tuscaloosa formation (Upper Cretaceous).
Reference.—Beikman and Drakoulis, 1958a, p. 55.

(26) *H. M. Ogg & H. A. Clark No. 1 G. Burkhalter*
Mississippi, Tallahatchee County; Sec. 27, T. 26 N., R. 3 E.
Elev. 357 ft.; T. D. 4,725 ft.; completed 1945.
Paleozoic rocks.—Top at 3,275 feet. A sample log by Mellen shows that rocks are depositionally and tectonically like the Ouachita facies and are intruded by felsic microgranites and rarer mafic sills and dikes (*F. F. Mellen, 1960*).
Overlain by Tuscaloosa formation (Upper Cretaceous).
Reference.—Beikman and Drakoulis, 1958a, p. 55.

The following additional wells in Tallahatchie County, are reported to have been drilled into the Paleozoic, but no information is available as to the nature of the rocks penetrated (Beikman and Drakoulis, 1958a, p. 55): Louisiana-Mississippi Oil Company No. 1 C. E. Shores; H. M. Ogg & H. A. Clark No. 1 D. G. Bardwell. Also, the following wells are reported to have been drilled into the Paleozoic in Leflore County to the south (Beikman and Drakoulis, 1958b; *P. L. Applin, 1960*): J. W. Hughes No. 1 Board of Supervisors and No. 1 McLemore.

(27) *W. L. Stewart et al. No. 1 W. W. Wood*
Mississippi, Grenada County; Sec. 19, T. 22 N., R. 5 E.
Elev. 213 ft.; T. D. 4,600 ft.; completed 1935.
Paleozoic rocks.—Top at 3,995 feet. Pennsylvanian(?) (Beikman and Drakoulis, 1958a). Rocks are of "Ouachita" facies (*H. J. Morgan, Jr., 1958*). As this well is considerably northeast of the Ouachita structural front as projected, the rocks penetrated are here interpreted as being deformed Pennsylvanian.
Overlain by Tuscaloosa(?) formation (Upper Cretaceous).
Reference.—Beikman and Drakoulis, 1958a, p. 24.

(28) *J. R. Lockhart No. 1 Guy Fite*
Mississippi, Grenada County; Sec. 25, T. 22 N., R. 6 E.
Elev. 322 ft.; T. D. 4,545 ft.; completed 1946.
Paleozoic rocks.—Top at 3,620 feet. Pennsylvanian (Beikman and Drakoulis, 1958a). A sequence of dark siliceous shale and siltstone with a few crinoid impressions and other fossil traces which suggest a Pennsylvanian age. Cores show steep dips (*F. F. Mellen, 1960*). See comment on well 27.
Overlain by Tuscaloosa formation (Upper Cretaceous).
Reference.—Beikman and Drakoulis, 1958a, p. 24.

(29) *Billups Bros. & Serio No. 1 N. H. Heath*
Mississippi, Carroll County; Sec. 29, T. 21 N., R. 4 E.
Elev. 270 ft.; T. D. 4,696 ft.; completed 1952.
Paleozoic rocks.—Top at 4,564 feet. Pennsylvanian (Beikman and Drakoulis, 1958a). The nature of the rocks penetrated is not recorded, but the well lies near the Ouachita structural front as projected. The rocks are here interpreted as Pennsylvanian in the deformed belt bordering the structural front.
Overlain by Lower(?) Cretaceous.
Reference.—Beikman and Drakoulis, 1958a, p. 14.

(30) *Billups Bros. No. 1 C. A. Townsend*
Mississippi, Montgomery County; Sec. 20, T. 19 N., R. 7 E.
Elev. 450 ft.; T. D. 4,564 ft.; completed 1952.
Paleozoic rocks.—Top at 4,545 feet. Pennsylvanian (Beikman and Drakoulis, 1958a). See comment on well 31.
Reference.—Beikman and Drakoulis, 1958a, p. 45.

(31) *Gulf Refining Company No. 1 F. W. Parker*
Mississippi, Montgomery County; Sec. 22, T. 19 N., R. 7 E.
Elev. 394 ft.; T. D. 5,303 ft.; completed 1940.

Paleozoic rocks.—Top at 4,480 feet. Pennsylvanian (Beikman and Drakoulis, 1958a). Of "Ouachita facies" (*H. J. Morgan, Jr., 1958*). A core from 4,637 to 4,652½ feet contains pelecypods and is a dark gray silty argillite, with stratification dipping about 15°. "Thin-section examination of the sample shows that the argillite is composed of a mass of dark clay and sericite containing fine quartz-feldspar silt, shreds of second-cycle muscovite, carbonaceous fragments, sporadic grains of pyrite, and spots of cryptocrystalline silica. The sericite forms a network of braided fibers, locally with two directions of orientation at a high angle. Possibly the oriented sericite indicates an incipient metamorphism" (*P. T. Flawn, 1960*). "The pelecypods are *Sanguinolites* sp. and *Nucula* or *Paleonucula* sp., neither of which is specifically determinable. Both genera range at least from Silurian through Permian. There is nothing about these specimens either to confirm or refute the Pennsylvanian age which has been ascribed to the beds" (*E. L. Yochelson, 1960*). Presumably the well is in the belt of deformed Pennsylvanian rocks northeast of the Ouachita structural front.

Overlain by Lower Cretaceous. The well is on the Kilmichael dome, a cryptovolcanic structure; Tertiary and Cretaceous beds are disturbed, but the top of the Paleozoic is at normal level.

References.—Priddy and McCutcheon, 1943, pp. 42–43; Beikman and Drakoulis, 1958a, p. 45.

The following additional well in Montgomery County is reported to have been drilled into the Paleozoic, but no information is available as to the nature of the rocks penetrated (Priddy and McCutcheon, 1943, p. 42; Beikman and Drakoulis, 1958a, p. 45) : Henderson Oil Company No. 1 Columbia Mutual Life.

(32) *Union Producing Company No. 1 J. N. Henderson*
Mississippi, Clay County; Sec. 22, T. 15 S., R. 4 E.
Elev. 437 ft.; T. D. 10,551 ft.; completed 1953.

Paleozoic rocks.—Top at 1,750 feet. Pennsylvanian to 9,763 feet, underlain by Mississippian (Chester series) to total depth. Samples indicate 54 coal zones in the Pennsylvanian, mainly thin, and electric log suggests possible presence of 93 zones. Twenty of these zones have yielded spores (Cropp, 1960, p. 362). Spores of the highest zone, at 1,950 feet, indicate a correlation with the upper Tradewater formation of Illinois and the upper Pottsville or basal Allegheny of the northern Appalachian area; spores of the lowest zone at 8,950 feet include only Pennsylvanian genera and no Mississippian genera. All the 8,013 feet of Pennsylvanian rocks in the well are clearly correlative with the Pottsville formation of the outcrops in Alabama to the east. This well, and well 33, are near the center of the Black Warrior basin, far northeast from the disturbed belt along the Ouachita structural front, yet south of the belt of shallow-lying Mississippian rocks of the northern part of the basin. North of the well the Pennsylvanian thins rapidly to 1,000 feet in less than 20 miles.

Overlain by Tuscaloosa formation (Upper Cretaceous).

References.—Beikman and Drakoulis, 1958a, p. 17; Cropp, 1960, pp. 361–366, fig. 3.

(33) *Atlantic Oil Company No. 1 R. G. Dunning*
Mississippi, Clay County; Sec. 12, T. 19 N., R. 16 E.
Elev. 184 ft.; T. D. 9,243 ft.; completed 1947.

Paleozoic rocks.—Top at 1,390 feet. Pottsville formation (Pennsylvanian) to 8,120 feet; Parkwood(?) formation to 8,610 feet; Chester series (Mississippian) to total depth. Published log (Dott and Murray, ed., 1954) indicates that the Pottsville is shale, sandstone that is conglomeratic in the lower 1,000 feet, and minor coal; the underlying Parkwood(?) is sandy shale. Thin sections were studied of cuttings at depths of 1,630, 1,650, 3,010, 3,170, 3,590, 3,700, 4,410, 7,490, and 8,170 feet (*August Goldstein, Jr., 1960*). The rocks are carbonaceous and micaceous shale, silty shale, and siltstone; and fine- to medium-grained sandstone (protoquartzite), well sorted, well washed, containing grains of quartz, metamorphic rocks (metaquartzite, phyllite, and mica schist), and detrital muscovite. Clearly, the rocks were derived from a metamorphic terrane, but they have not themselves been metamorphosed. See comments on well 32.

Overlain by Tuscaloosa formation (Upper Cretaceous).

References.—Dott and Murray, ed., 1954, sheet 1, well 6; Beikman and Drakoulis, 1958a, p. 17.

(34) *N. W. Shiarella No. 1 L. L. Murphy*
Mississippi, Oktibbeha County; Sec. 28, T. 17 N., R. 12 E.
Elev. 450 ft.; T. D. 4,024 ft.; completed 1940.

Paleozoic rocks.—Top at 3,640 feet. Pottsville formation (Pennsylvanian) to total depth. Published log (Dott and Murray, ed., 1954) indicates that Pottsville is shale and sandy shale.

Overlain by Lower Cretaceous.

References.—Dott and Murray, ed., 1954, sheet 1, well 5; Beikman and Drakoulis, 1958a, p. 47.

The following additional wells in Oktibbeha County are reported to have been drilled into the Pennsylvanian, but no information is available as to the nature of the rocks penetrated (Beikman and Drakoulis, 1958a, p. 47): John Allen No. 1 W. C. Howell; McAlester Fuel Company No. 1-A Sudduth. Also, the following are reported to have been drilled into the Pennsylvanian in Choctaw County to the west (Beikman and

Drakoulis, 1958a, p. 15) : Henson & Rife No. 1 W. J. & T. W. Green and No. 1 Stafford, Copeland & Stafford.

(35) *Shell Oil Company No. 1 H. H. Wheeles*
Mississippi, Attala County; Sec. 5, T. 14 N., R. 9 E.
Elev. 511 ft.; T. D. 6,217 ft.; completed 1945.

Paleozoic rocks.—Top at 5,504 feet. Pottsville formation (Pennsylvanian) to total depth (Dott and Murray, ed., 1954; Beikman and Drakoulis, 1958a). Classed by some geologists as of "Ouachita" facies. Published log shows that the Pennsylvanian is shale and sandy shale. Thin sections were studied of cuttings and cores from depths of 5,635, 5.847, 5,950, 6,010, 6,080, and 6,160 feet (*August Goldstein, Jr., 1960; P. T. Flawn, 1959*). Most of the rocks are dark carbonaceous shale, largely silty, partly calcareous. In one specimen (6,080 feet) laminae of quartzose feldspathic siltstone alternate with laminae of silty carbonaceous shale. Part of the clay in the shales is unaltered, but as much as half or more has been recrystallized to chlorite and minor sericite. One specimen (5,635 feet) is dark, laminated, sublithographic limestone, veined by quartz. All the specimens show incipient to very low grade metamorphism. "Finely divided and disseminated organic matter reduces the apparent metamorphic grade of the rock. Without this, these rocks might have been equal in metamorphic grade to those in Stanolind No. 1 Steed farther west in the county" (*Goldstein*). The rocks are comparable in metamorphic grade to many of those in the Ouachita belt, but they are interpreted here as part of the belt of deformed Pennsylvanian rocks close to the structural front.

Overlain by 1,780 feet of Lower Cretaceous.

References.—Dott and Murray, ed., 1954, sheet 1, well 4; Beikman and Drakoulis, 1958a, p. 13.

(36) *Continental Oil Company No. 1 H. O. Fortenberry*
Mississippi, Neshoba County; Sec. 13, T. 12 N., R. 10 E.
Elev. 453 ft.; T. D. 5.915 ft.; completed 1952.

Paleozoic rocks.—Top at 5,740 feet. Reported to be Pennsylvanian black shale of "Ouachita" facies. As this well lies a short distance northeast of the belt of older Paleozoic carbonate rocks, its rocks are here interpreted as Pennsylvanian that has been deformed along the edge of this belt and not as part of the main Ouachita belt.

Overlain by Lower Cretaceous(?).

Reference.—Beikman and Drakoulis, 1958a, p. 46.

(37) *H. W. Elliott et al. No. 1 Mrs. Laura Eakes*
Mississippi, Neshoba County; Sec. 36, T. 11 N., R. 13 E.
Elev. 503 ft.; T. D. 5,427 ft.; completed 1950.

Paleozoic rocks.—Top at 5,364 feet. Pennsylvanian (Beikman and Drakoulis, 1958a). Reported to be of "Ouachita" facies. See comment on well 36.

Overlain by Lower Cretaceous.

Reference.—Beikman and Drakoulis, 1958a, p. 46.

(38) *Magnolia Petroleum Corporation No. 1 C. Culpepper*
Mississippi, Lauderdale County; Sec. 4, T. 8 N., R. 14 E.
Elev. 426 ft.; T. D. 6,256 ft.; completed 1941.

Paleozoic rocks.—Top at 6,060 feet. Undifferentiated Paleozoic (Beikman and Drakoulis, 1958a). Reported to be Pennsylvanian of "Ouachita" facies. See comment on well 36.

Overlain by Lower Cretaceous.

Reference.—Beikman and Drakoulis, 1958a, p. 39.

In addition to these, the following wells are reported to have been drilled into the Paleozoic in Kemper County to the east, but no information is available as to the nature of the rocks penetrated (Beikman and Drakoulis, 1958a, p. 37) : R. A. Lamb & S. G. Galt No. 1 Phillips Estate; E. B. LaRue No. 1 Edmund Longshore.

(39) *C. H. Murphy, Jr., No. 1 R. E. Eaton*
Alabama, Pickens County; Sec. 34, T. 19 S., R. 16 W.
Elev. 315 ft.; T. D. 5,503 ft.; completed 1946.

Paleozoic rocks.—Top at 940 feet. Pottsville formation (Pennsylvanian) to total depth. Sample log shows a monotonous sequence of gray and black micaceous or sandy shale, with some beds of sandstone, occasional coal beds, and one bed of crinoidal limestone.

Overlain by Tuscaloosa formation (Upper Cretaceous).

References.—Mellen, 1947, fig. 8, p. 1813; Applin, 1951, p. 22, table 3, well 35; McGlamery, 1955, pp. 369–379.

(40) *L. M. Glasco No. 1 J. A. Norwood*
Alabama, Greene County; Sec. 17, T. 23 N., R. 1 W.
Elev. 211 ft.; T. D. 5,510 ft.; completed 1957.

Paleozoic rocks.—Top at 1,865 feet. Reported to have drilled in Pennsylvanian to total depth, but little information is available (*P. L. Applin, 1960*).
Overlain by Lower Cretaceous(?).

(41) *Stanolind Oil & Gas Company No. 1 G. B. Sandel*
Alabama, Tuscaloosa County; Sec. 2, T. 18 S., R. 9 W.
Elev. 600 ft.; T. D. 5,410 ft.; completed 1943.
Paleozoic rocks.—Paleozoic at surface. Pottsville formation (Pennsylvanian) to 2,985 feet; shale and sandstone, with some coal beds and marine fossiliferous layers. Underlain to total depth by limestone and sandy limestone, with traces of fossils. Driller's log reports these underlying strata to be Bangor limestone (Mississippian) (Toulmin, 1945), but sample examination indicates that they are probably Ordovician (McGlamery, 1955). The well is in the Wiley or Friedman dome, which has about 300 feet of closure in the Pennsylvanian; superposition of Pennsylvanian on Ordovician suggests a periodic uplift of this feature before the final doming.
References.—Toulmin, 1945, pp. 133–135; McGlamery, 1955, pp. 380–389; Jones, 1960, pp. 89–90.

Mississippian and Pennsylvanian(?)

(42) *A. Gutowsky et al. No. 1 Ada Mills*
Arkansas, Little River County; Sec. 18, T. 12 S., R. 29 W.
Elev. 328 ft.; T. D. about 4,300 ft.; completed before 1943.
Paleozoic rocks.—Top at about 2,700 feet. "Folded Paleozoics of Ouachita facies"; no data are given as to their character.
Overlain by Hosston formation (Lower Cretaceous). Published section shows a thin intervening wedge of Eagle Mills formation.
Reference.—Hazzard and others, 1947, section A-A′.

(43) *Boettcher No. 1 State Life Insurance Company*
Arkansas, Howard County; Sec. 28, T. 11 S., R. 27 W.
Elev. 292 ft.; T. D. 2,936 ft.; completed 1937.
Paleozoic rocks.—Penetrated 750 feet of hard tight sand, with streaks of carbonaceous shale. Lithologically, the sandstone suggests Jackfork formation, but the black shale streaks may indicate Atoka formation.
Overlain by Hosston formation (Lower Cretaceous), with basal chert conglomerate.
References.—Weeks, 1938, p. 962; Swain, 1944, p. 589, fig. 7.

(44) *S. S. Alexander No. 1 Smythe*
Arkansas, Calhoun County; Sec. 7, T. 11 S., R. 14 W.
Elev. 263 ft.; T. D. about 4,000 ft.; completed 1938.
Paleozoic rocks.—Top at about 2,500 feet. "Folded Paleozoics of Ouachita facies"; no data are given as to their character.
Overlain by Ozan and Tokio formations of Late Cretaceous (Austin) age.
Reference.—Hazzard and others, 1947, section B-B′.

Besides these wells, Weeks (1938, p. 962) mentions one in Sec. 25, T. 9 S., R. 19 W., Clark County, which penetrated 610 feet of black carbonaceous shale, with streaks of tight fine sand and some gray and brown limestone, probably Atoka formation; and another in Sec. 36, T. 10 S., R. 11 W., Cleveland County, that penetrated 100 feet of tight sand and black shale, probably Early Pennsylvanian or Mississippian. Imlay (1940a, section C-C′) indicates that Ohio Oil Company No. 1 Taylor, Sec. 27, T. 9 S., R. 17 W., Dallas County, entered "folded Paleozoics" at a depth of 1,698 feet but does not show their character. Spooner (1935, p. 334) states that in Grant County to the north, the Paleozoic rocks penetrated in the half-dozen wells drilled prior to 1935 "consists chiefly of light-colored to gray quartzitic sandstone and dark gray slaty shale."

Although records for the wells classed as "Mississippian and Pennsylvanian(?)" are incomplete, some or all of them probably penetrated Stanley shale and Jackfork sandstone of Mississippian age, and perhaps also Atoka formation of Pennsylvanian age.

Devonian to Cambrian of Appalachian System

(45) *Carter Oil Company No. 1 Denkman*
Mississippi, Leake County; Sec. 31, T. 11 N., R. 7 E.
Elev. 449 ft.; T. D. 9,408 ft.; completed 1952.

Paleozoic rocks.—Top at 8,728 feet. Apparently most of the sequence is carbonate rocks. Poorly preserved brachiopods occur in a core at 9,356 to 9,379 feet, which are *Coelospira* sp. and *Stricklandia* sp., of Silurian age (*G. A. Cooper, 1952,* letter to Rizer Everett). No information is available as to whether Paleozoic formations of other ages overlie or underlie the Silurian strata.

Overlain by Cotton Valley group (Jurassic).

Reference.—Beikman and Drakoulis, 1958a, p. 40.

(46) *Southeastern Drilling Company No. 1 L. D. Eley et al.*
Mississippi, Scott County; Sec. 19, R. 8 N., T. 8 E.
Elev. 383 ft.; T. D. 9,814 ft.; completed 1952.

Paleozoic rocks.—Top at 9,458 feet. Cambro-Ordovician (Beikman and Drakoulis, 1958a). Red calcareous dolomitic chert, much like that in well 45 from which Cooper identified Silurian fossils; probably not Cambro-Ordovician (*F. F. Mellen, 1960*).

Overlain by Cotton Valley group (Jurassic).

Reference.—Beikman and Drakoulis, 1958a, p. 51.

(47) *Slick Oil Company & Plains Producing Company No. 1 J. D. Breazeale*
Mississippi, Neshoba County; Sec. 28, T. 12 N., R. 10 E.
Elev. 398 ft.; T. D. 6,132 ft.; completed 1947.

Paleozoic rocks.—Top at 5,825 feet. Cambro-Ordovician cherty dolomite to total depth.

Overlain by Lower Cretaceous.

References.—Dott and Murray, ed., 1954, sheet 1, well 3; Beikman and Drakoulis, 1958a, p. 46.

(48) *Pure Oil Company No. 1 J. D. Jones*
Mississippi, Neshoba County; Sec. 19, T. 11 N., R. 13 E.
Elev. 493 ft.; T. D. 5,610 ft.; completed 1951.

Paleozoic rocks.—Top at 5,381 feet. Reported to be Ordovician dolomite.

Overlain by Lower Cretaceous(?).

Reference.—Beikman and Drakoulis, 1958a, p. 46.

(49) *Pure Oil Company No. 1 A. S. Rea*
Mississippi, Neshoba County; Sec. 36, T. 11 N., R. 12 E.
Elev. 527 ft.; T. D. 5,519 ft.; completed 1950.

Paleozoic rocks.—Top at 5,510 feet. Reported to be Ordovician dolomite.

Overlain by Lower Cretaceous(?).

Reference.—Beikman and Drakoulis, 1958a, p. 46.

(50) *Southern Natural Gas Company No. 1 J. W. Smith*
Mississippi, Neshoba County; Sec. 1, T. 9 N., R. 11 E.
Elev. 557 ft.; T. D. 6,876 ft.; completed 1943.

Paleozoic rocks.—Top at 6,450 feet. Cambro-Ordovician limestone, sandy limestone, and dolomite to total depth.

Overlain by Lower Cretaceous.

References.—Dott and Murray, ed., 1954, sheet 1, well 2; Beikman and Drakoulis, 1958a, p. 46.

(51) *Sun Oil Company No. 1 Citizens National Bank*
Mississippi, Newton County; Sec. 23, T. 5 N., R. 13 E.
Elev. 389 ft.; T. D. 8,340 ft.; completed 1945.

Paleozoic rocks.—Top at 8,300? feet. Ordovician dolomite to total depth. Samples from 8,300 and 8,306 feet are red, fine-grained, calcareous dolomite and fine-grained dolomite of lower Paleozoic type (*P. T. Flawn, 1959*). Samples are reported to suggest faulting or folding.

Overlain by Cotton Valley group (Jurassic).

Reference.—Beikman and Drakoulis, 1958a, p. 46.

(52) *Sun Oil Company No. 1 Hilma Wall*
Mississippi, Newton County; Sec. 28, T. 5 N., R. 13 E.
Elev. 406 ft.; T. D. 10.117 ft.; completed 1943.

Paleozoic rocks.—Top at 8,761 feet. Cambro-Ordovician limestone with some dolomite and sandy dolomite in lowest 300 feet.

Overlain by Cotton Valley group (Jurassic).

References.—Dott and Murray, ed., 1954, sheet 1, well 1; Beikman and Drakoulis, 1958a, p. 46.

(53) *Marott No. 1 Larkin*
Alabama, Sumter County; Sec. 34, T. 20 N., R. 2 W.
Elev. 204 ft.; T. D. 4.590 ft.; completed 1955.

Paleozoic rocks.—Top at 3,082 feet. Knox dolomite (Cambro-Ordovician) reported to total depth.

(54) *Johnson & Hawkins Company No. 1 Willis*
Alabama, Greene County; Sec. 11, T. 20 N., R. 1 E.
Elev. 130 ft.; T. D. 2.616 ft.; completed 1940.

Paleozoic rocks.—Top at 2,350 feet. Driller's log records "hard lime" and "hard sandy lime" to total depth. At first reported to be Mississippian, including Fort Payne (Bowles, 1941) but later assigned to the Ordovician(?) (Shreveport Geol. Soc., 1947). The assignment of the rocks to the Ordovician(?) is more compatible with the regional relations.

Overlain by Lower Cretaceous.

References.—Bowles, 1941, pp. 151–152; Shreveport Geological Society, 1947, pl. 3; Applin, 1951, p. 22, table 3, well 29.

(55) *E. C. Johnston No. 1 H. D. Peteet*
Alabama, Marengo County; Sec. 3, T. 16 N., R. 2 E.
Elev. 247 ft.; T. D. 4,523 ft.; completed 1944.

Paleozoic rocks.—Top at 3,872 feet. Driller's log records "lime" and "hard gray lime" to total depth. with cores at 3,927, 4,209, 4,291, and 4,523 feet. Cores contain fossils of high Black River or of Trenton age (*G. A. Cooper, 1944,* letter to Alabama Geological Survey).

Overlain by Lower Cretaceous.

References.—Toulmin, 1945, pp. 114–116; Applin and Applin, 1947, sheet 2, fig. 10, well 26; sheet 3, text; Applin, 1951, p. 22, table 3, well 34.

Devonian to Cambrian of Ouachita System

(56) *A. L. Kitselman, No. 2 Fee*
Arkansas, Pulaski County; Sec. 2, T. 1 S., R. 13 W.
Elev. 250 ft.; T. D. 4,080 ft.; completed 1938.

Paleozoic rocks.—Paleozoic at 250 feet. Driller's log and sample examinations by W. B. Weeks are available. "The rocks are greatly deformed and metamorphosed; descriptions of cuttings show they contain much vein quartz and are cut by several dikes of igneous rocks. Apparently the drill passed through the Arkansas novaculite from 792–1,132 feet, possibly the Missouri Mountain slate in the next 200 feet, possibly the Polk Creek shale from 1,400–1,700 or 1,800 feet, possibly the Bigfork chert to 3,600 feet or beyond" (*H. D. Miser, 1938,* letter to Arkansas Geological Survey). This well is only a few miles from outcrops of Devonian and older rocks at the east end of the Ouachita Mountains.

Overlain by Midway(?) formation.

References.—Caplan, 1954, p. 12; log and sample report from *Arkansas Geological and Conservation Commission, 1960.*

Devonian to Cambrian of Suwanee Basin

(57) *Union Producing Company No. 1 E. P. Kirkland*
Alabama, Houston County; Sec. 20, T. 7 N., R. 11 W.
Elev. 140 ft.; T. D. 8,100 ft.; completed 1949.

Paleozoic rocks.—Top at 7,556 feet. Quartzitic gray sandstone and black micaceous shale to total depth, containing graptolites of Early Ordovician (Canadian) age. The rocks in this well are the only ones in which graptolites have been found in the Suwanee basin (*Jean Berdan, 1960*).

Overlain by 566 feet of Triassic(?) clastic rocks.

References.—Applin, 1951, p. 22, table 3, well 30; Bridge and Berdan, 1951, 1952; McKee and others, 1959, pl. 4.

(58) *Mont Warren et al. No. 1 A. C. Chandler*
Georgia, Early County; Lot 406, Land Dist. 26.
Elev. 181 ft.; T. D. 7,320 ft.; completed 1943.

Paleozoic rocks.—Top at 6,600 to 6,607 feet is a weathered zone composed of dull brick-red, finely sandy, somewhat micaceous shale containing molds and impressions of small bivalves. First black shale fragments occur in cuttings at about 6,780 feet. Quartzitic sandstone was penetrated from 7,240 feet to total depth. Black shale at 6,995 to 7,015 feet contains *Chevroleperditia chevronalis,* a new genus and species of ostracode, originally interpreted from its stage of evolution to be of Late Ordovician or Early Silurian age (Swartz, 1949). Subsequently, J. M. Schopf has determined plant spores from the same horizon as not older than Middle Devonian, and the ostracodes are compatible with this age. No fossils have been recovered from the lower part of the black shale or the sandstone beneath it.

Overlain by 930 feet of Triassic(?) clastic rocks.

References.—Applin and Applin, 1947, sheet 1, fig. 2, well 61; Swartz, 1949, p. 320; Applin, 1951, p. 25, table 3, well 73; Bridge and Berdan, 1951, 1952; McKee and others, 1959, pl. 4; revisions by *P. L. Applin and Jean Berdan, 1960.*

(59) *Humble Oil & Refining Company No. 1 Bennett & Langsdale*
Georgia, Echols County; Lot 146, Land Dist. 12.
Elev. 181 ft.; T. D. 4,185 ft.; completed 1949.

Paleozoic rocks.—Top at 4,120 feet; weathered? shale. Paleozoic rocks are intruded by one or more sills of diabase of Triassic(?) age from 4,125 to 4,150 feet, with shale beneath to total depth. The shale is tentatively correlated with micaceous shale and quartzitic sandstone which have yielded Early Ordovician (Canadian) fossils in well 57 (Bridge and Berdan, 1951, 1952).

Overlain by Lower Cretaceous(?).
References.—Applin, 1951, p. 16, p. 25, table 3, p. 27, table 4, well 74; Bridge and Berdan, 1951, 1952.

(60) *Hunt Oil Company No. 4 Superior Pine Products Company*
Georgia, Echols County; Lot 219, Land Dist. 13.
Elev. 156 ft.; T. D. 3,916 ft.; completed 1948.
Paleozoic rocks.—Top at 3,911 feet. Red micaceous silty shale, probably in a weathered zone, containing linguloid brachiopods of Middle Ordovician age.
Overlain by Lower Cretaceous(?).
References.—Applin, 1951, p. 25, table 3, well 78; Bridge and Berdan, 1951, 1952.

(61) *Hunt Oil Company No. 1 Superior Pine Products Company*
Georgia, Echols County; Lot 364, Land Dist. 13.
Paleozoic rocks.—Top at 3,782 feet. Black or dark gray shale with some reddish streaks, containing fragments of the inarticulate brachiopod *Trematis*, identified by Bridge and Cooper; this genus ranges from Middle to Late Ordovician in age (*Jean Berdan, 1960*).
Overlain by Lower Cretaceous(?).
References.—Applin, 1951, p. 25, table 3, well 75; Bridge and Berdan, 1951, 1952.

(62) *Humble Oil & Refining Company No. 1 C. W. Tindel*
Florida, Jackson County; Sec. 8, T. 5 N., R. 11 W.
Elev. 128 ft.; T. D. 9,245 ft.; completed 1949.
Paleozoic rocks.—Top at 8,440 feet. Red, brown, and gray, cross-bedded sandstone and shale to total depth, probably of fresh-water or continental origin, from which plant fragments and spores of probable Middle Devonian age have been identified by Serge Mamay and J. M. Schopf (*Jean Berdan, 1960*). Two basalt sills occur in the Paleozoic rocks at depths of 8,890 to 8,932 and 8,970 to 8,983 feet.
Overlain by about 220 feet of Triassic(?) clastic rocks.
References.—Applin, 1951, p. 23, table 3, p. 26, table 4, well 53; Bridge and Berdan, 1951, 1952; McKee and others, 1959, pl. 4.

(63) *Coastal Petroleum Company No. 1 E. P. Larsh*
Florida, Jefferson County; Sec. 1, T. 2 S., R. 3 E.
Elev. 51 ft.; T. D. 7,913 ft.; completed 1949.
Paleozoic rocks.—Top at 7,909 feet. White quartzitic sandstone without fossils but possibly of Early Ordovician age.
Overlain by 810 feet of clastic rocks of Triassic(?) age, with diabase sills or dikes at 7,763 to 7,792 and 7,850 to 7,890 feet.
References.—Applin, 1951, p. 23, table 3, p. 26, table 4, well 54; Bridge and Berdan, 1951, 1952; McKee and others, 1959, pl. 4.

(64) *Hunt Oil Company No. 2 J. W. Gibson*
Florida, Madison County; Sec. 6, T. 1 S., R. 10 E.
Elev. 107 ft.; T. D. 5,385 ft.; completed 1944.
Paleozoic rocks.—Top at 4,628 feet. Black shale to total depth, containing a trilobite and some linguloid brachiopods of probable early Middle Ordovician (Chazyan) age.
Overlain by diabase from 4,589 to 4,628 feet, and this by Lower Cretaceous or older Mesozoic rocks.
References.—Applin, 1951, p. 24, table 3, p. 26, table 4, well 62; Bridge and Berdan, 1951, 1952; Whittington, 1953.

(65) *Hunt Oil Company No. 4 J. W. Gibson*
Florida, Madison County; Sec. 5, T. 2 S., R. 11 E.
Elev. 73 ft.; T. D. 4,096 ft.; completed 1945.
Paleozoic rocks.—Top at 4,060 feet. Black quartzitic sandstone with worm borings, and shale, probably of Early Ordovician (Canadian) age.
Overlain by diabase from 4,044 to 4,060 feet, and this by Lower Cretaceous or older Mesozoic rocks.
References.—Applin, 1951, p. 24, table 3, p. 26, table 4, well 63; Bridge and Berdan, 1951, 1952.

(66) *Humble Oil & Refining Company No. 1 R. L. Henderson*
Florida, Lafayette County; Sec. 20, T. 4 S., R. 11 E.
Elev. 52 ft.; T. D. 4,235 ft.; completed 1948.
Paleozoic rocks.—Top at 4,192 feet, with weathered zone to 4,205 feet. Penetrated a boulder zone containing red and yellow quartzite pebbles and ended in hard white to gray unfossiliferous quartzite of uncertain but probable early Paleozoic age.
Overlain by Lower Cretaceous(?).
References.—Applin, 1951, p. 24, table 3, well 57; Bridge and Berdan, 1951, 1952.

(67) *Gulf Oil Corporation No. 1 Brooks-Scanlon, Inc., Block 49*
Florida, Lafayette County; Sec. 36, T. 5 S., R. 10 E.
Elev. 87 ft.; T. D. 4,512 ft.; completed 1949.

Paleozoic rocks.—Top at 4,505(?) feet. Quartzitic sandstone to total depth. May be pebbles or boulders of early Paleozoic rock incorporated in Cretaceous or earlier Mesozoic conglomerate, or may be a Paleozoic formation. There is no information either way, as maximum penetration of the quartzite was only 7 feet.

Overlain by Lower Cretaceous(?)

References.—Applin, 1951, p. 23, table 3, well 56; Bridge and Berdan, 1951, 1952.

(68) *Sun Oil Company No. 1 P. C. Crapps*
Florida, Lafayette County; Sec. 25, T. 6 S., R. 12 E.
Elev. 70 ft.; T. D. 4,133 ft.; completed 1946.

Paleozoic rocks.—Top at 3,993; weathered zone to 4,030 feet. Unfossiliferous quartzitic sandstone and shale, probably of Early Ordovician (Canadian) age.

Overlain by Lower Cretaceous(?).

References.—Applin, 1951, table 3, well 58; Bridge and Berdan, 1951, 1952.

For wells which entered Paleozoic rocks in the Suwanee basin south and east of the map area, in Florida and Georgia, see Applin (1951) and Bridge and Berdan (1951, 1952).

Weakly Metamorphosed Rocks

(69) *Fohs-Loffland Bros. No. 1 Louis Miller*
Arkansas, Arkansas County; Sec. 33, T. 5 S., R. 4 W.
Elev. 190 ft.; T. D. 4,560 ft.; completed 1940.

Paleozoic(?) rocks.—Top at 4,518 feet. Driller's log records "gray slaty schist" to total depth. Core at 4,550 to 4,560 feet is described as "gray slate and schist, graphitic in spots." The degree of metamorphism implied by the driller's record suggests that the rocks may be of Ouachita facies (Caplan, 1954).

Overlain by "Eutaw" (Tokio formation) (Upper Cretaceous).

References.—Renfroe, 1949, pp. 20–21; Caplan, 1954, p. 13.

(70) *Holman & Russell No. 1 E. K. Thomas*
Mississippi, Bolivar County; Sec. 18, T. 24 N., R. 7 W.
Elev. 159 ft.; T. D. 4,659 ft.; completed 1941.

Paleozoic(?) rocks.—Top at 4,587 feet. Rocks are of "Ouachita" facies (*H. J. Morgan, Jr., 1958*). This well is close to the Ouachita structural front as projected and only a few miles southwest of No. 1 Knowlton & Perthshire (well 24) which is here interpreted as of foreland facies. The rocks in the Thomas well are here placed in the metamorphic unit, but with doubt.

Reference.—Beikman and Drakoulis, 1958a, p. 14.

(71) *The Texas Company No. 1 E. G. Whitehead et al.*
Mississippi, Carroll County; Sec. 22, T. 18 N., R. 5 E.
Elev. 342 ft.; T. D. 5,283 ft.; completed 1948.

Paleozoic(?) rocks.—Top at 5,215 feet. Undifferentiated Paleozoic (Beikman and Drakoulis, 1958a). Reported to be "metamorphic schist." This well lies close to the Ouachita structural front as projected, and the "schist" is compatible with the weakly metamorphosed rocks penetrated in Attala County to the south (wells 72 and 73). According to C. E. Weaver (fig. 7, p. 148) the clays from this well have a "sharpness ratio" of more than 5.0, the highest recorded in Mississippi, and comparable to clays of the interior zone of the Ouachita belt in Texas.

Overlain by Lower Cretaceous(?).

Reference.—Beikman and Drakoulis, 1958a, p. 14.

(72) *Stanolind Oil & Gas Company No. 1 C. E. Steed*
Mississippi, Attala County; Sec. 4, T. 13 N., R. 6 E.
Elev. 329 ft.; T. D. 7,108 ft.; completed 1947.

Paleozoic(?) rocks.—Top at 6,724 feet. Thin sections were studied from depths of 6,700, 6,705, 6,805, 6,815, 6.886, 6,905, 6,995, 7,075, and 7,085 feet (*August Goldstein, Jr., 1960*). Most of the specimens are chert, cherty clay-slate, and clay-slate, but there is one specimen (6,805 feet) of siliceous limestone and another of metaquartzite (6,905 feet). The cherts are variably argillaceous, dolomitic, and calcareous, and grade into cherty or siliceous slate. The whole suite was probably a high-silica shale before metamorphism, but half or more of the clay has been recrystallized to chlorite and sericite; metamorphism is weak to low grade (muscovite-chlorite subfacies of green schist facies). In some of the cherts are monaxon sponge spicules that have been recrystallized and partly resorbed, but no other fossils are visible. "These cuttings are comparable in metamorphic grade to rocks of Ouachita facies along the Balcones fault zone in central Texas. It is not possible to assign them to a definite formation, but their general aspect is Ordovician(?)" (*Goldstein*).

Overlain by Lower Cretaceous.

Reference.—Beikman and Drakoulis, 1958a, p. 13.

(73) *Continental Oil Company No. 1 Millard Sudduth*
Mississippi, Attala County; Sec. 28, T. 13 N., R. 6 E.
Elev. 342 ft.; T. D. 8,018 ft.; completed 1952.

Paleozoic(?) rocks.—Top at 7,249 feet. Rocks are weakly metamorphosed but strongly sheared black slate. Cores were examined from depths of 7,080, 7,601, 7,798, and 7,970 feet (*Josiah Bridge, 1953; P. T. Flawn, 1959*). They are carbonaceous or graphitic clay-slate, containing abundant mica and chlorite, well foliated and in places with incipient fracture cleavage or microfaults. Foliation crosses bedding at angles of 20° to 40°. In one core (7,970 feet) thin layers of black graphitic slate alternate with thin layers of fine-grained dolomite, in which the carbonate grains are stretched and twinned. Quartz veinlets, dolomite veinlets, and pyrite are common; one core (7,798 feet) is a breccia of angular vein quartz fragments, cemented by limestone and shale. Metamorphism is weak but with a strong shearing element. The cores were searched for fossils without result, but the general aspect of the rocks would seem to be like that of the older Paleozoic formations of Ouachita facies.

Overlain between 7,018 and 7,249 feet by altered porphyry, in which feldspar laths are changed to clay; flowage structure in the groundmass suggests that the rock was extrusive. The porphyry is overlain in turn by Lower Cretaceous.

Reference.—Beikman and Drakoulis, 1958a, p. 13.

(74) *Gulf Refining Company No. 49 Louis Werner Sawmill Company*
Arkansas, Union County; Sec. 5, T. 16 S., R. 16 W.
Elev. 128 ft.; T. D. 7,973 ft.; completed 1935.

Paleozoic rocks.—Top at 7,600 feet. "Mudstone" or "hornfels"; hard, dense, silicified, reddish to purplish, dipping 15° to 20°, intruded by diabase. From the available record it seems likely that much or all of the metamorphism is related to the igneous intrusion.

Overlain with basal conglomerate by Werner formation, of which this is its type section. The well is on the Louann dome in the Smackover oil field.

References.—Imlay, 1940, p. 10; Hazzard and others, 1947, pp. 486–487, section B-B′.

(75) *Phillips Petroleum Company No. 1 J. T. Arnold*
Arkansas, Ouachita County; Sec. 27, T. 15 S., R. 15 W.
Elev. 208 ft.; T. D. about 7,000 ft.; completed 1936.

Paleozoic rocks.—Top at about 6,700 feet, with igneous rocks near total depth; no data are given as to nature of the Paleozoic rocks, but they may resemble the rocks in well 74.

Overlain by Werner formation. The well is in the Smackover oil field.

Reference.—Imlay, 1940, section E-E′.

Farther northeast in Cleveland County, Spooner (1935, pp. 392–394) reports that Arkansas Natural Gas Company No. 1 Tate, Sec. 4, T. 9 S., R 11 W., penetrated altered pre-Mesozoic rocks at 3,310 feet which, according to C. S. Ross, are shale, limestone, and possibly chert, intruded and contact-metamorphosed by peridotite. The description suggests the older Paleozoic rocks of the Ouachita Mountains.

Metamorphic and Plutonic Rocks

(76) *Gulf Refining Company No. 1 C. C. Sellers*
Alabama, Wilcox County; Sec. 13, T. 11 N., R. 7 E.
Elev. 182 ft.; T. D. 7,575 ft.; completed 1952.

Metamorphic rocks.—Top at 7,422 feet. Reported to be "schist."

Overlain by pre-Smackover Jurassic rocks.

(77) *Seaboard Oil Company No. 1 S. M. McConnico*
Alabama, Wilcox County; Sec. 32, T. 12 N., R. 10 E.
Elev. 186 ft.; T. D. 5,780 ft.; completed 1945.

Metamorphic rocks.—Top at 5,518 feet. Granite gneiss to total depth.

Overlain by Lower Cretaceous or older Mesozoic rocks.

Reference.—Applin, 1951, p. 19, table 1, well 4.

(78) *Seaboard Oil Company No. 1 J. T. Rollins*
Alabama, Wilcox County; Sec. 16, T. 12 N., R. 10 E.
Elev. 152 ft.; T. D. 5,449 ft.; completed 1958.

Metamorphic rocks.—Top at 5,220 feet. Weathered schist to 5,313 feet, schist to total depth (*P. L. Applin, 1960*).

Overlain by Cotton Valley group(?) and Lower Cretaceous.

(79) *Montgomery Oil Company No. 1 Snowdown*
Alabama, Montgomery County; Sec. 29 or 30, T. 15 N., R. 18 E.
Elev. 222 ft.; T. D. 2,007 ft.; completed 1922.

Metamorphic rocks.—Top at 1,995 feet. Crystalline rock to total depth.
Overlain by Tuscaloosa formation (Upper Cretaceous).
References.—Bowles, 1941, pp. 158–159; Applin, 1951, p. 19, table 1, well 3.

(80) *Gulf Refining Company No. 1 D. A. Hendrix*
Alabama, Butler County; Sec. 26, T. 7 N., R. 13 E.
Elev. 440 ft.; T. D. 9,480 ft.; completed 1952.
Metamorphic rocks.—Top at 9,460 feet. Logged as "diorite schist" (*P. L. Applin, 1960*). Cores from 9,460 to 9,480 feet were examined (*Charles Milton, 1952; P. T. Flawn, 1960*). Milton identified the rock as rhyolite tuff and rhyolite porphyry tuff. According to Flawn, "The sample is an altered volcanic rock composed largely of sericite, calcite, chlorite, and epidote, with corroded remnants of plagioclase phenocrysts, and sporadic smaller quartz phenocrysts. The sericite fibers which compose most of the groundmass may be inherited from a pre-existing flow structure or they may form a foliation imposed by regional metamorphism. Well developed smooth planar surfaces make an angle of about 45° with the core wall." The felsic nature of this igneous rock distinguishes it from the mafic igneous rocks of Triassic(?) age in the same area, and it is here interpreted as part of the basement complex of the Piedmont. The rock may be comparable to felsic volcanic rocks penetrated by wells in southeastern Georgia (well 88, below, and Applin, 1951, pp. 8–11).
Overlain by about 781 feet of red conglomerate, sandstone, and shale, with basalt at top, probably Triassic(?), and this by Lower Cretaceous. Core at 8,679 to 8,688 feet is olivine basalt, core at 8,727 to 8,737 feet is coarse arkosic conglomerate (*Charles Milton, 1952; P. T. Flawn, 1960*).

(81) *Alabama Oil Development Company No. 1 Jacob Hill*
Alabama, Pike County; Sec. 35, T. 8 N., R. 19 E.
Elev. 438 ft.; T. D. 2,691 ft.; completed 1928.
Metamorphic rocks.—Top at 2,665 feet. Logged as "graphitic mica schist." This reported penetration of metamorphic rocks requires verification, as it is at surprisingly shallow depth, compared with sequences in wells 1 and 80 adjacent to the west, where thick bodies of Triassic(?) rocks underlie the Cretaceous.
Overlain by Tuscaloosa formation.
Reference.—Bowles, 1941, pp. 245–247.

(82) *Capitol Oil & Gas Company No. 1 Ethel B. Gholston*
Alabama, Bullock County; Sec. 18, T. 14 N., R. 22 E.
Elev. 270 ft.; T. D. 1,714 ft.; completed 1945.
Metamorphic rocks.—Top at 1,703 feet. Logged as "granite gneiss" but termed "diorite gneiss" by Applin (1951).
Overlain by Lower Cretaceous.
References.—Toulmin, 1945, pp. 19–20; Applin and Applin, 1947, sheet 1, fig. 6, well 3; Applin, 1951, p. 5, p. 19, table 1, well 1.

(83) *Capitol Oil & Gas Company No. 1 Fred Pickett*
Alabama, Bullock County; Sec. 22, T. 13 N., R. 21 E.
Elev. 430 ft.; T. D. 2,523 ft.; completed 1945.
Metamorphic rocks.—Top at 2,502 feet. Metamorphic rock, probably gneiss, to total depth; no cores taken.
Overlain by Lower Cretaceous.
References.—Toulmin, 1945, pp. 21–23; Applin and Applin, 1947, sheet 1, fig. 6, well 4; Applin, 1951, p. 19, table 1, well 2.

(84) *Southeastern Operator's Committee No. 1 Mrs. Beatrice Gamble & O. A. Gamble*
Alabama, Henry County; Sec. 13, T. 4 N., R. 28 E.
Elev. 304 ft.; T. D. 6,395 ft.; completed 1952.
Metamorphic(?) rocks.—Core at 6,391 to 6,394 feet is granophyre, which might be a marginal phase of either a granite batholith or of a large body of diabase or gabbro (*Charles Milton, 1952*). Information is not available as to the nature of the overlying rocks. Considerable thicknesses of Triassic(?) clastic rocks and mafic igneous rocks are penetrated in nearby wells. The granophyre might be an unusual differentiate of one of the mafic igneous bodies, but its depth is comparable to that of pre-Mesozoic rocks in the vicinity.

(85) *Tricon Minerals, Inc., No. 1 J. D. Duke*
Georgia, Houston County; Lot 44, Land Dist. 14.
Elev. 419 ft.; T. D. 1,494 ft.; completed 1949.
Metamorphic rocks.—Top at 1,490 feet. Biotite gneiss to total depth.
Overlain by Tuscaloosa(?) formation (Upper Cretaceous).
Reference.—Applin, 1951, p. 5, 19, table 1, well 9.

(86) *Tricon Minerals, Inc., No. 1 H. B. Gilbert*
Georgia, Houston County; Lot 266, Land Dist. 13.
Elev. 367 ft.; T. D. 1,698 ft.; completed 1949.
Metamorphic rocks.—Top at 1,685 feet. Biotite gneiss to total depth.

Overlain by Tuscaloosa(?) formation (Upper Cretaceous).
Reference.—Applin, 1951, pp. 5, 19, table 1, well 10.

(87) *Middle Georgia Oil & Gas Company*
Georgia, Washington County; 12 miles northwest of Sandersville.
Elev. 300 ft.; T. D. 400 feet; completed 1920.
Metamorphic rocks.—In crystalline rock to total depth.
Overlain by Tuscaloosa formation (Upper Cretaceous). This well is only a few miles south of outcrops of metamorphic rocks in the Piedmont province.
References.—Richards, 1945, p. 926; Applin, 1951, p. 20, table 1, well 28.

(88) *Sun Oil Company No. 1 Doster-Ladson*
Georgia, Atkinson County; Lot 71, Land Dist. 7.
Elev. 222 ft.; T. D. 4,296 ft.; completed 1945.
Metamorphic rocks.—Top at 4,220 feet. Volcanic tuff or agglomerate composed of hydrothermally altered rhyolite.
Overlain by Lower Cretaceous. Similar rhyolitic volcanic rocks were penetrated in a well in Camden County, Georgia, to the east, suggesting the existence of a belt of these rocks along the northeast edge of the Suwanee basin of Paleozoic rocks.
Reference.—Applin, 1951, pp. 9, 21, table 2, well 27.

For additional wells which entered metamorphic and plutonic rocks in Georgia east of the map area, see Applin (1951, pp. 19–21, tables 1–2).

Plates 5-15

PLATE 5

Photomicrographs of lower Paleozoic Ouachita facies rocks from the frontal zone of the Ouachita belt

A. Bituminous dolomitic spiculitic chert (Bigfork chert, Stringtown quarry, Atoka County, Oklahoma). x63

B. Bituminous dolomitic spiculitic chert (Bigfork chert, Sun Oil Company No. 1 Tucker, Fannin County, Texas, 3,820 to 3,830 feet, p. 256). x63

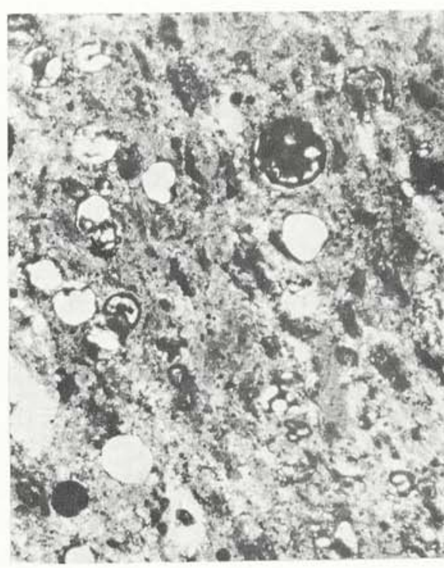
C. Dolomitic chert (lower Paleozoic Ouachita facies, Mellon Oil Company No. 1 Noah Bailey, Bell County, Texas, 3,575 to 3,580 feet, p. 218). x91

D. Bituminous radiolarian-bearing chert (lower Paleozoic Ouachita facies rocks, Roland Blumberg No. 1 D. C. Knibbe, Comal County, Texas, 1,535 to 1,540 feet, p. 243). x82

A

B

C



D

PLATE 6

Photomicrographs of sandstone from the Stanley shale in the frontal zone of the Ouachita belt

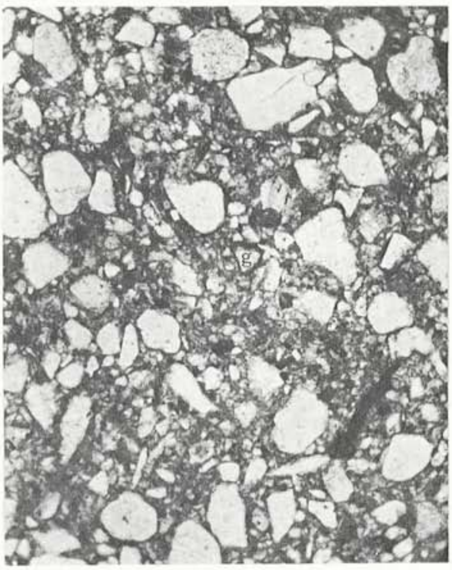
A. Fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone (Ouachita Mountains, 32–1S–12E, NW/4, NW/4, Atoka County, Oklahoma). x56

B. Fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone (Texas Minerals No. 1 Snowden, Fannin County, Texas, 3,395 to 3,425 feet, p. 256). x49

C. Fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone (Shell Oil Company No. 1 C. E. Massie, Bell County, Texas, 850 to 860 feet, p. 221). x56

D. Fine-grained, angular, poorly sorted, argillaceous feldspathic quartz sandstone (Midcoast (B. R. Floyd) No. 1 E. A. Jones, Travis County, Texas, 695 to 700 feet, p. 315). x49

g = garnet



A

B

C

D

PLATE 7

Photomicrographs of Mississippian-Pennsylvanian sandstone (including sandstone from the Tesnus formation) from the frontal zone of the Ouachita belt

A. Fine- to medium-grained, angular to subround, poorly sorted, argillaceous feldspathic quartz sandstone (Tesnus formation, Persimmon Gap, Brewster County, Texas). x49

B. Fine- to medium-grained, mostly angular, poorly sorted, calcareous argillaceous feldspathic quartz sandstone containing abundant rock fragments (Bernard Einstoss No. 1 Roswell Wardlaw, Uvalde County, Texas, 1,853 to 1,857 feet, p. 317). x49

C. Fine-grained, angular, poorly sorted, argillaceous micaceous feldspathic quartz sandstone veined by quartz (General Crude Oil Company No. 1 J. H. Talley, Bexar County, Texas, 2,615 to 2,622 feet, p. 225). x56

D. Fine-grained, subangular to subround poorly sorted, feldspathic argillaceous quartz sandstone (Roland Blumberg No. 1 D. C. Knibbe, Comal County, Texas, 2,930 feet, p. 243). x56

A

B

C

D

PLATE 8

Photomicrographs of rocks from the frontal zone of the Ouachita belt

A. Radiolarian tests and spicules in shale (Jackfork sandstone, Cox Drilling Corporation No. 1 S. F. Leslie, Fannin County, Texas, 4,100 to 4,110 feet, p. 254). x63

B. Cone-in-cone limestone (Stanley shale, Peter Oil and Gas Co., Inc., No. 1 Butcher, Grayson County, Texas, 3,340 feet, p. 262). x24

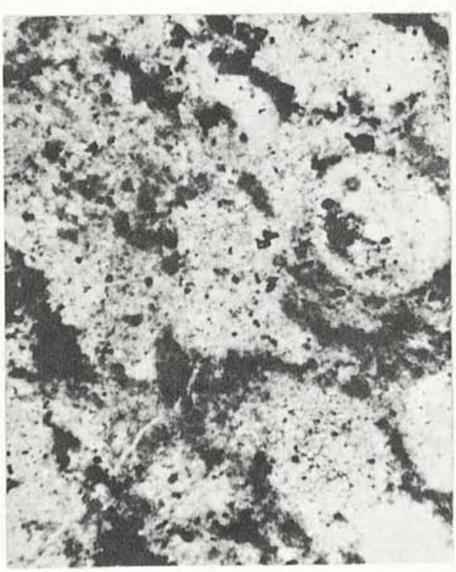
C. Radiolarian(?) tests in chert (lower Paleozoic Ouachita facies rock, General Crude Oil Company No. 1 Earnest Day, Coryell County, Texas, 6,870 to 6,880 feet, p. 246). x105

D. Sheared calcite marble (metamorphosed lower Paleozoic Ouachita facies rocks, Johnston Petroleum Syndicate No. 1 Lady Alice, Red River County, Texas, 4,000 to 4,033 feet, p. 301). x42, crossed nicols

sc = stretched calcite

A

B



C

D

PLATE 9

Photomicrographs of rocks from the frontal and interior zones of the Ouachita belt close to the Luling front

A. Carbonaceous clay-slate extensively veined with quartz (dark clastic unit in the interior part of the frontal zone, City of Austin No. 1 Blunn Creek, Travis County, Texas, 2,246 feet, p. 312). x14, crossed nicols

B. Strongly deformed black graphitic slate containing broken quartz veins (interior zone, General Crude Oil Company No. 1 Rogers Ranch, Bexar County, Texas, 2,676 feet, p. 224). x49

C. Strongly deformed graphitic black slate containing augen of broken quartz veins and slate fragments (interior zone, Woodward No. 1 Schubert, Hays County, Texas, 3,333 to 3,338 feet, p. 272). x18

D. Strongly deformed black graphitic slate containing broken quartz veins (interior zone, Stanolind Oil and Gas Company No. 1 Schmidt, Guadalupe County, Texas, Core No. 38, p. 269). x49

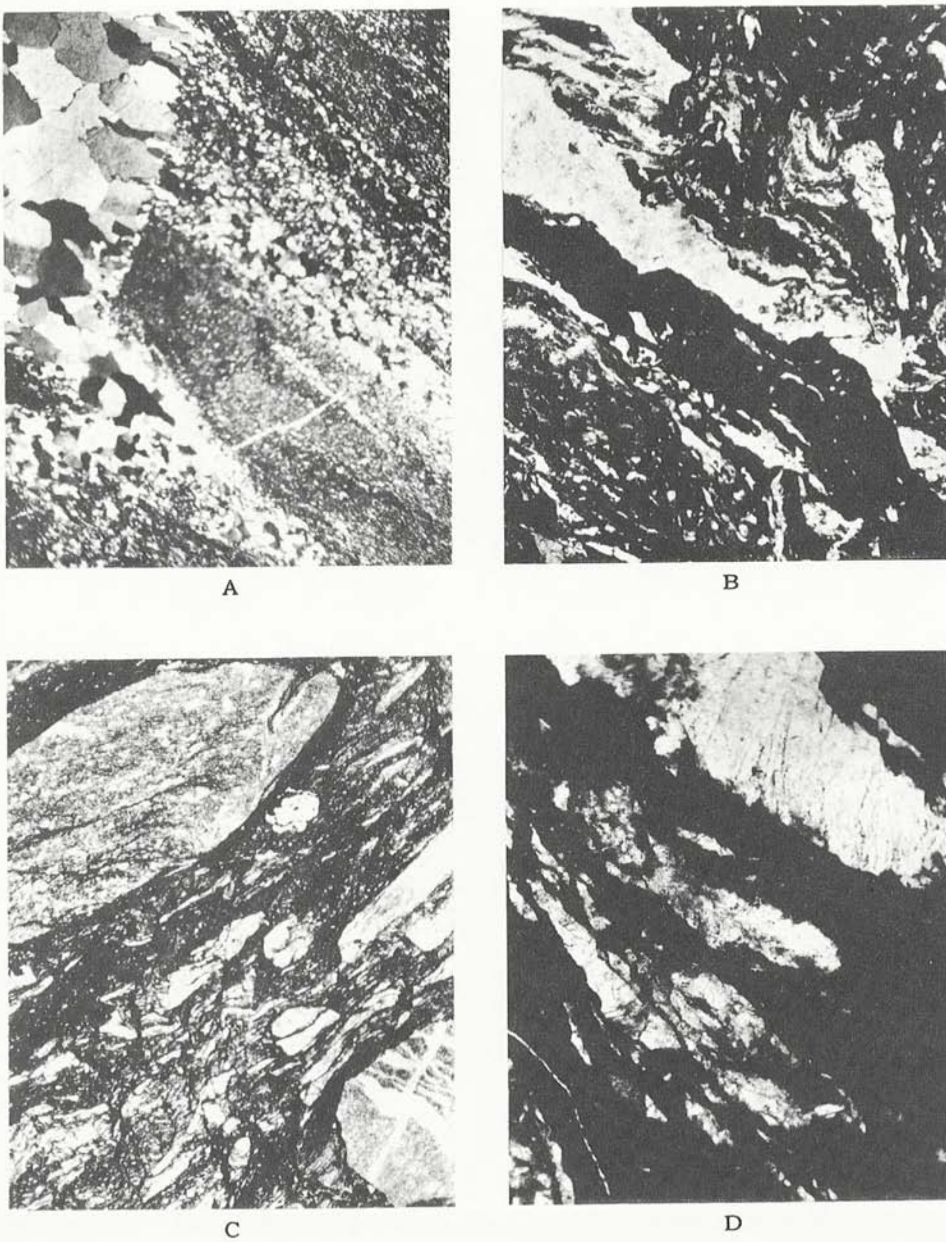


PLATE 10

Photomicrographs of low-grade metamorphic rocks from the interior zone of the Ouachita belt

A. Chloritic sericite phyllite veined with quartz (John B. Coffee No. 1 Nelson Davis, Milam County, Texas, 3,729 to 3,759 feet, p. 297). x28, crossed nicols

B. Sheared graphitic sericite-chlorite phyllite (Skelly Oil Company and Sunray Midcontinent Oil Company No. 1 Cornell, Lee County, Texas, 6,745 to 6,750 feet, p. 288). x28

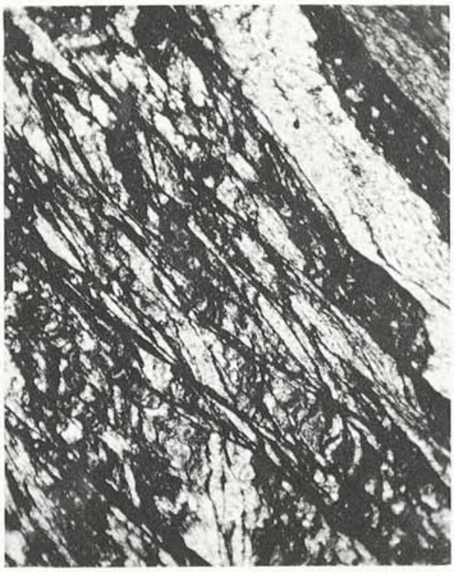
C. Fracture cleavage in sericite phyllite (United North and South Development Company No. 8 W. H. Tabor, Caldwell County, Texas, 4,331 feet, p. 240). x46

D. Graphitic calcite marble (Plumber and Schwab No. 1 Bud Roark, Brewster County, Texas, 2,804 feet, p. 235). x49, crossed nicols

$\longleftarrow$ B $\longrightarrow$ = Bedding

sc = stretched calcite

A



B

C

D

PLATE 11

Photomicrographs of metamorphosed rocks from the Ouachita belt

A. Metaquartzite or metachert (interior zone, Joiner Oil Corporation No. 1 Sellars (Sellers) Bros. Ranch, Val Verde County, Texas, 1,950 to 1,955 feet, p. 325). x80, crossed nicols

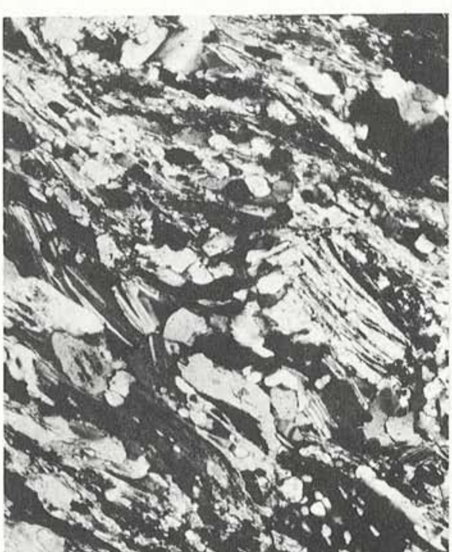
B. Calcite marble (interior zone, D. Henry Werblow and Associates No. 1 Maude S. Newton, Val Verde County, Texas, 5,300 to 5,310 feet, p. 331). x58, crossed nicols.

C. Fine-grained chlorite-mica-albite schist (Sierra del Carmen, Coahuila, Mexico, p. 99). x35, crossed nicols

D. Chlorite-sericite slate (Tesnus? frontal zone, Southwest Texas Oil and Gas Association No. 1 A. T. Folsom, Terrell County, Texas, 3,580 feet, p. 309). x42, crossed nicols

A

B



C

D

PLATE 12

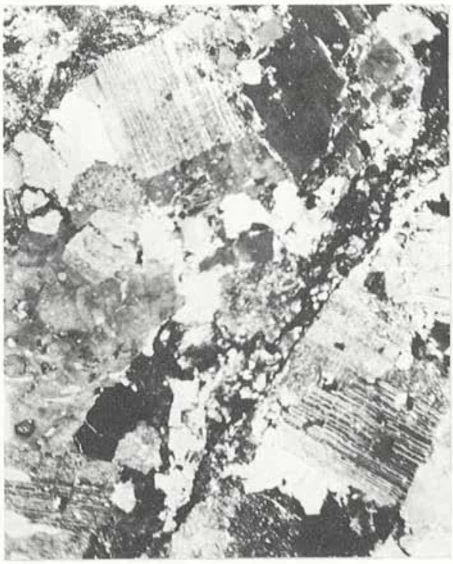
Photomicrographs of igneous rocks from the interior zone of the Ouachita belt

A. Cataclastically altered biotite granite (Humble Oil & Refining Company No. 1 E. E. Wilson, Medina County, Texas, 7,065 to 7,068 feet, p. 295). x15, crossed nicols

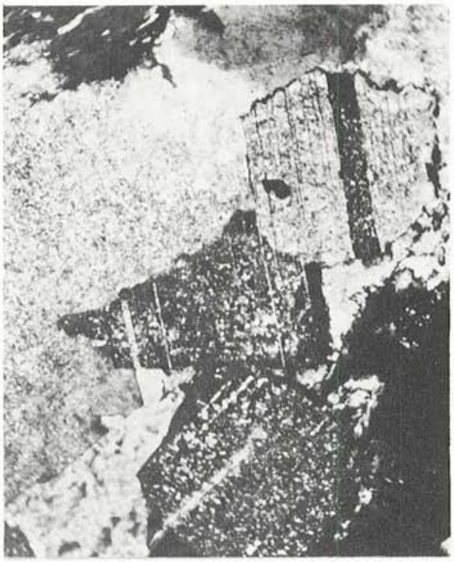
B. Cataclastically-altered granodiorite from an augen in black slate (General Crude Oil Company No. 1 Rogers Ranch, Bexar County, Texas, 5,713 feet, p. 224). x49, crossed nicols

C. Altered andesite porphyry (Humble Oil & Refining Company No. 1 E. E. Wilson, Medina County, Texas, 7,161 to 7,166 feet, p. 295). x15, crossed nicols

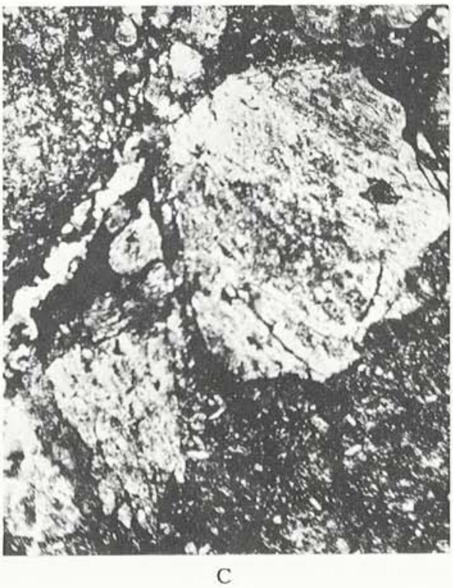
D. Spilitic basalt porphyry (Humble Oil & Refining Company No. 1 Bandera County School Land, Maverick County, Texas, 13,523 to 13,528 feet, p. 290). x46,crossed nicols



A



B



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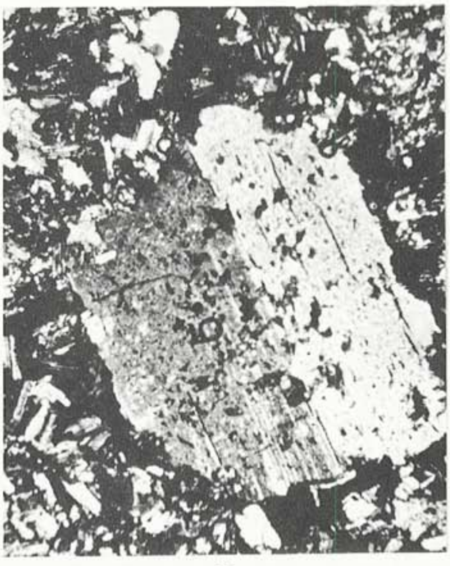


D

PLATE 13

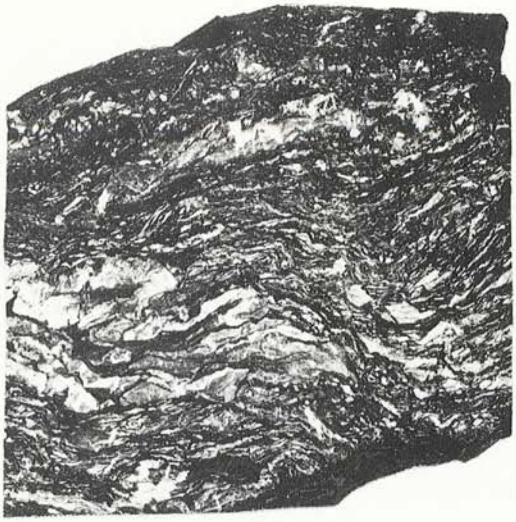
Cores of strongly deformed black slate from the interior zone of the Ouachita belt immediately south of the Luling front. General Crude Oil Company No. 1 Rogers Ranch, Bexar County, Texas
(pp. 224–225)

(All ⅔ natural size)

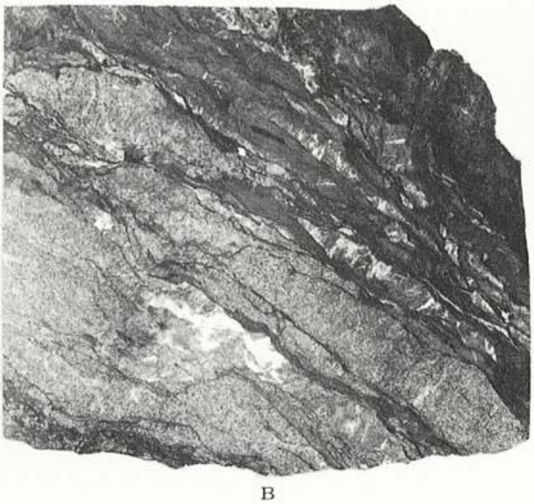
A. Black slate containing broken and contorted quartz veins (3,160 feet).

B. Black slate and dark slaty metasiltstone (3,263 feet).

C. Dark slaty metasiltstone containing augen of altered granodiorite at top (5,713 to 5,723 feet).



A



B

C

PLATE 14

Cores of strongly deformed black slate from the interior zone of the Ouachita belt immediately south of the Luling front

(All ⅔ natural size)

A. Black slate containing broken and contorted quartz veins (Stanolind Oil and Gas Company No. 1 Schmidt, Guadalupe County, Texas, Core No. 38, p. 269).

B. Black slate (same as A, p. 269).

C. Dark slaty metasiltstone (Woodward No. 1 Schubert, Hays County, Texas, 3,297 to 3,305 feet, p. 272).

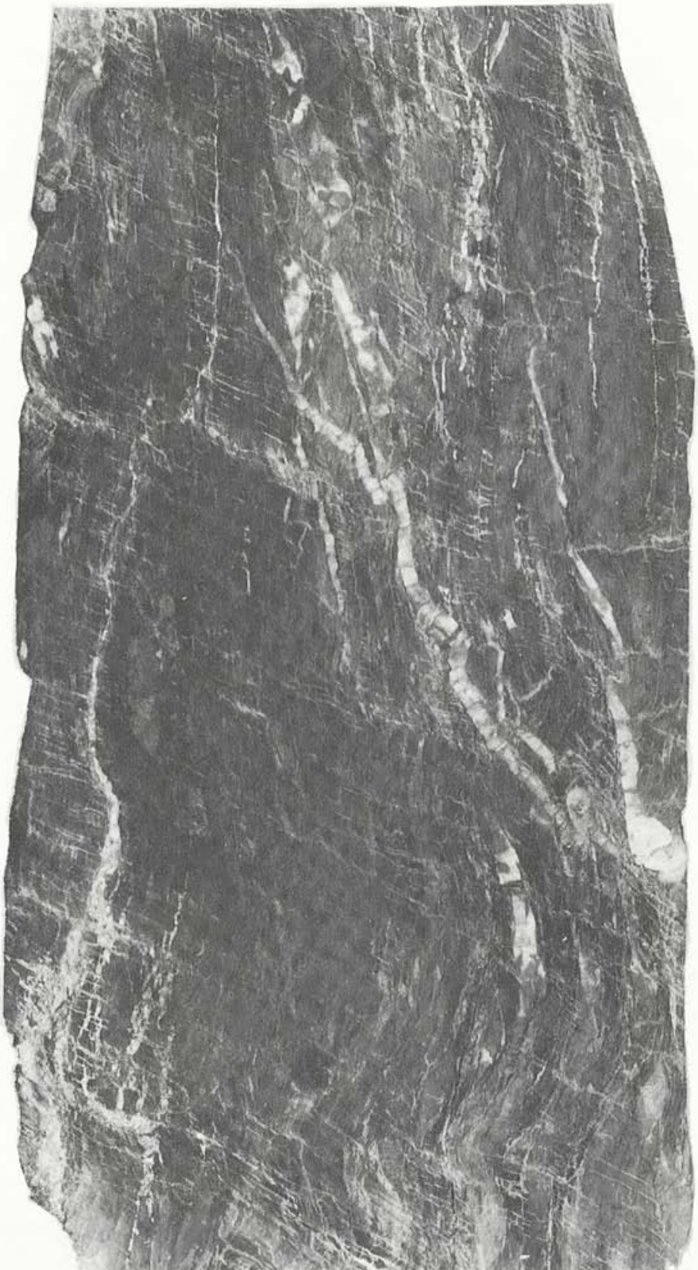
A

B

C

PLATE 15

Core of chloritic sericite phyllite from the interior zone of the Ouachita belt (John B. Coffee No. 1 Nelson Davis, Milam County, Texas, 3,729 to 3,759 feet, p. 297). Natural size.



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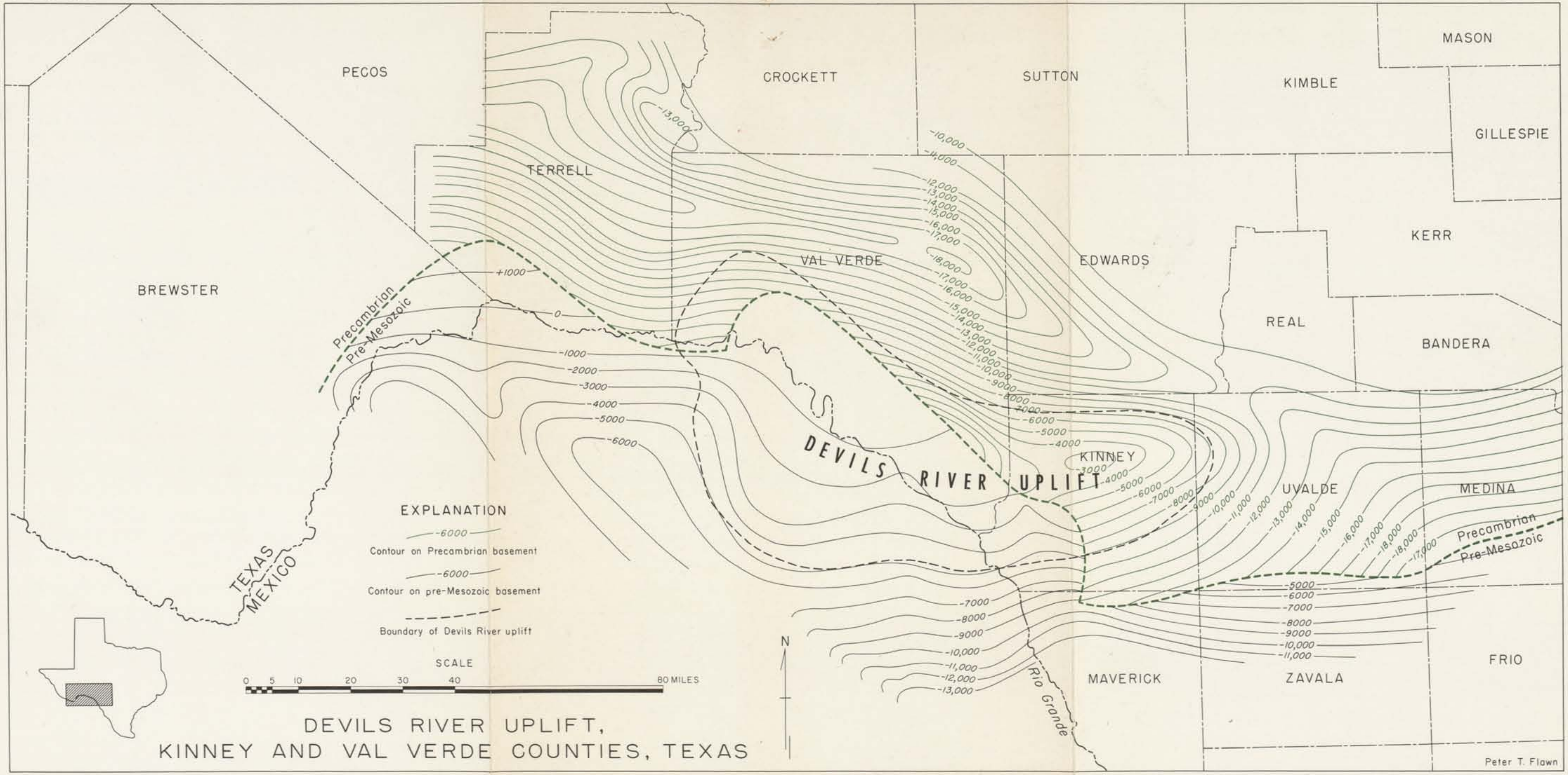
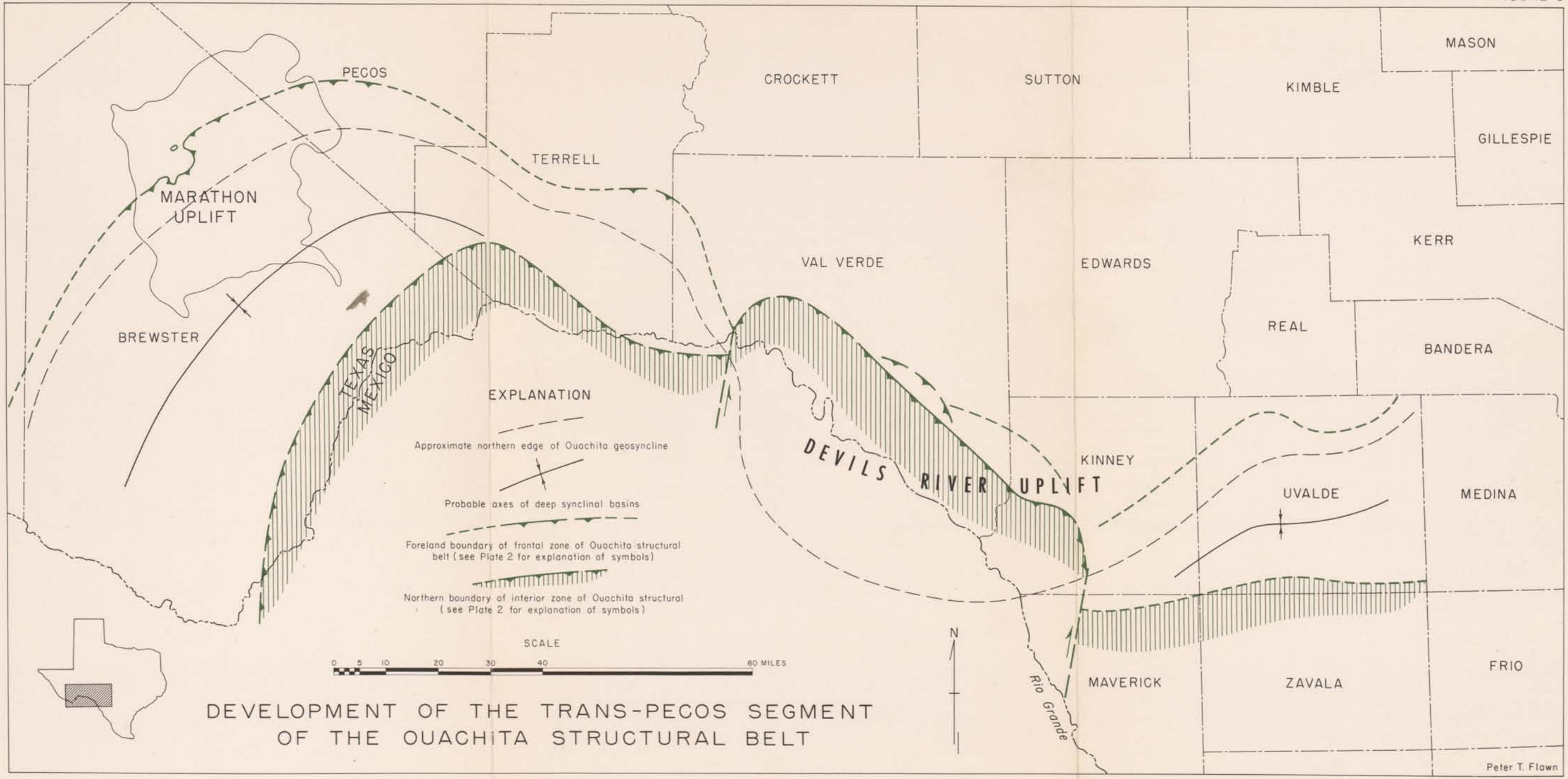


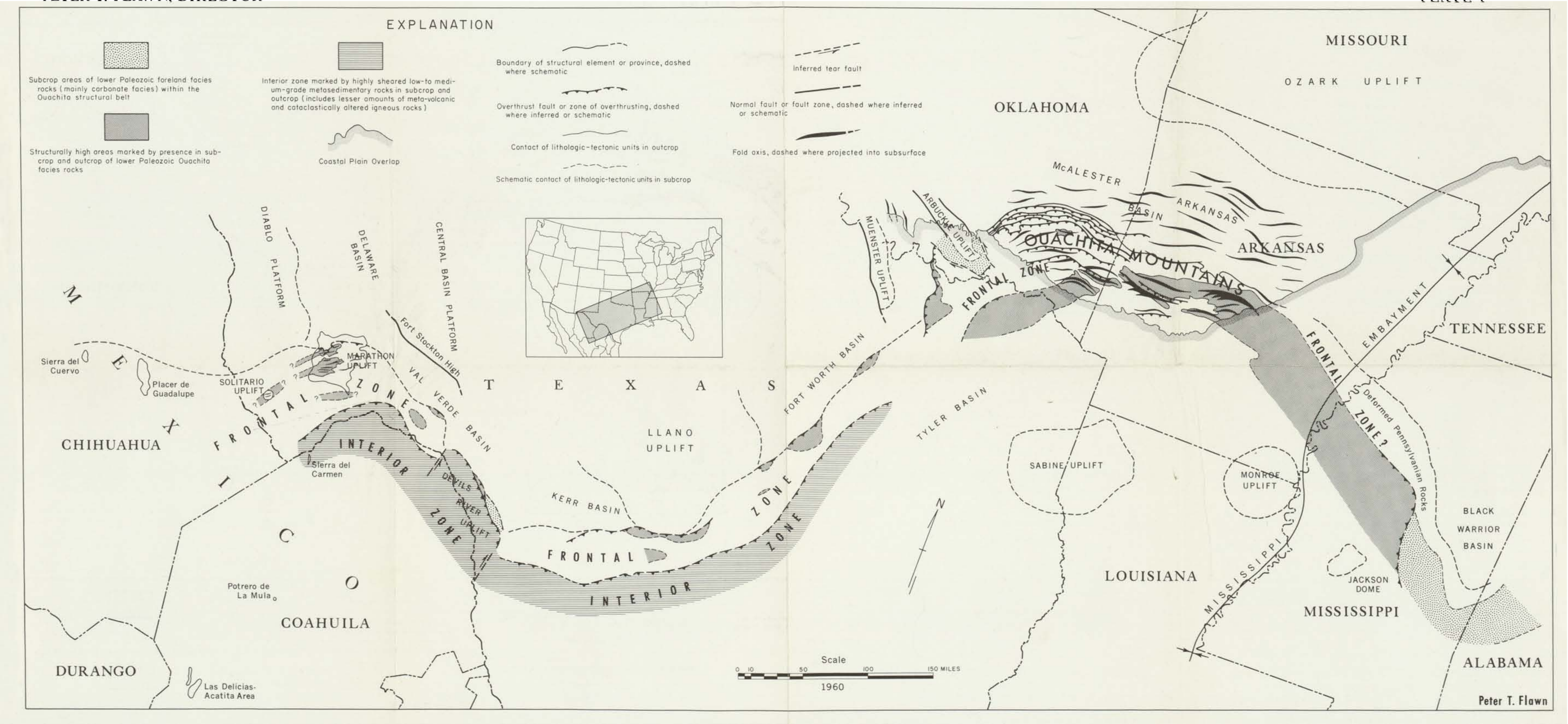
DEVILS RIVER UPLIFT,
KINNEY AND VAL VERDE COUNTIES, TEXAS



DEVELOPMENT OF THE TRANS-PECOS SEGMENT OF THE OUACHITA STRUCTURAL BELT

THE UNIVERSITY OF TEXAS
BUREAU OF ECONOMIC GEOLOGY
PETER T. FLAWN, DIRECTOR

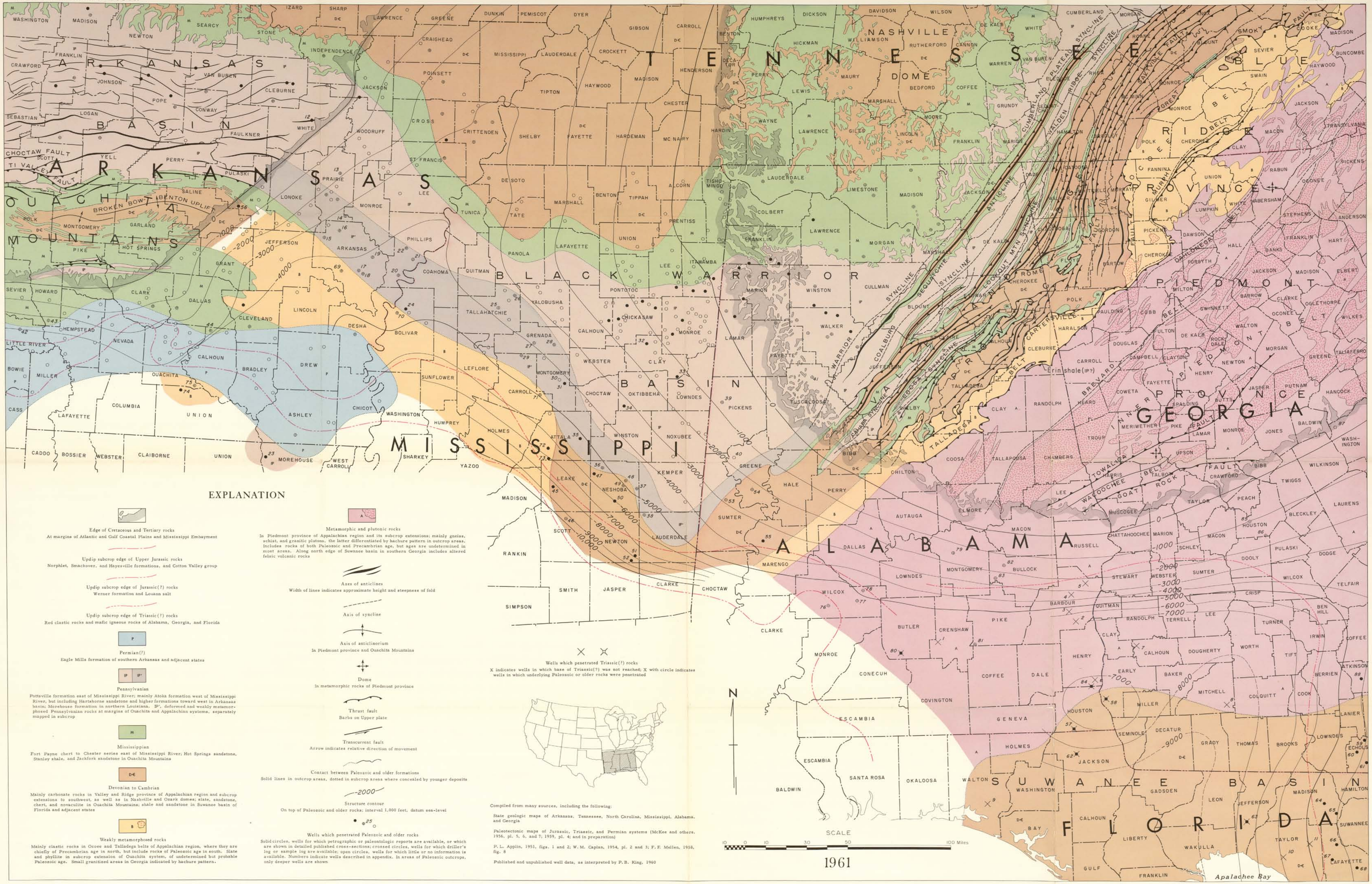
THE OUACHITA SYSTEM
PLATE 1



THE OUACHITA SYSTEM
REGIONAL STRUCTURAL MAP

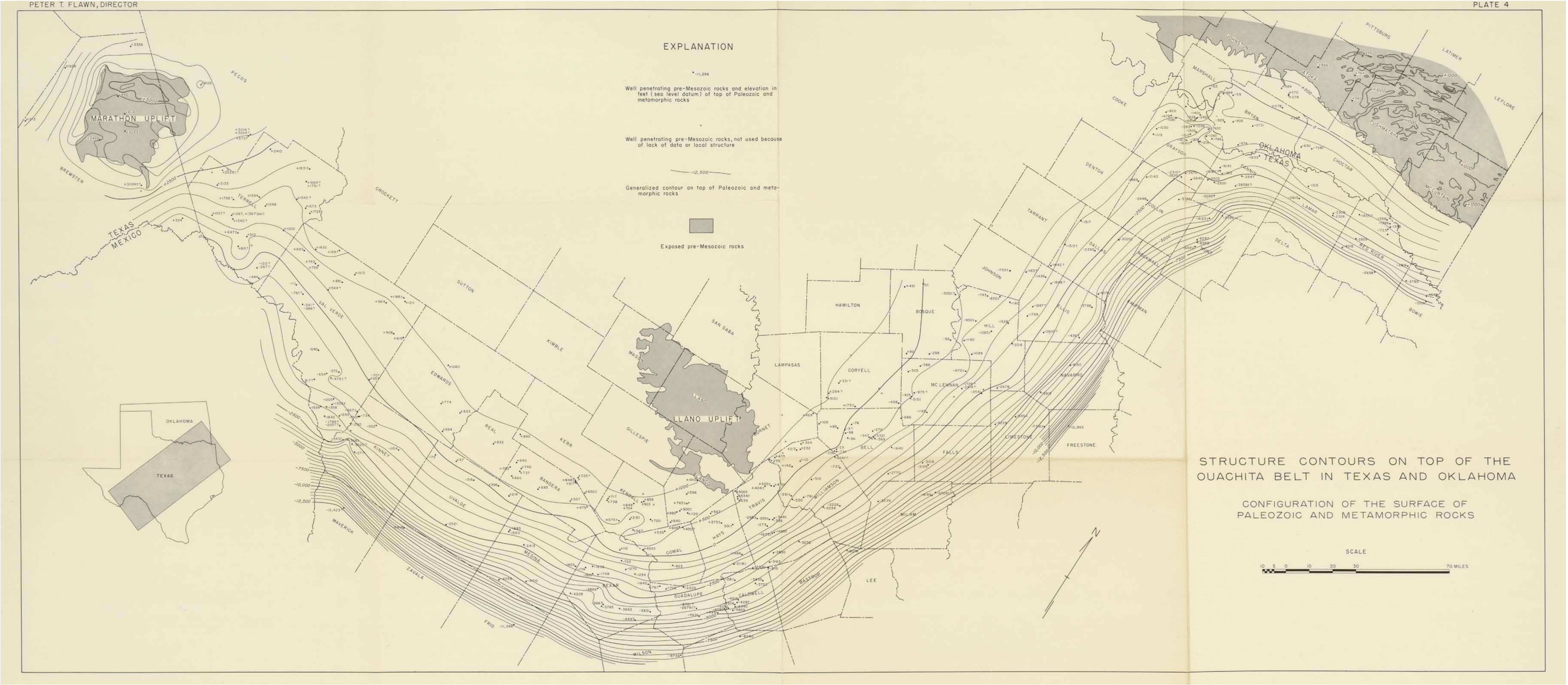
GEOLOGIC MAP OF THE OUACHITA STRUCTURAL BELT IN TEXAS AND OKLAHOMA

Peter T. Flawn



GEOLOGIC MAP OF PART OF SOUTHEASTERN UNITED STATES SHOWING OUTCROP AND SUBCROP AREAS OF PALEOZOIC AND OLDER ROCKS

Philip B. King


EXPLANATION
-11,296
Well penetrating pre-Mesozoic rocks and elevation in feet (sea level datum) of top of Paleozoic and metamorphic rocks
Well penetrating pre-Mesozoic rocks, not used because of lack of data or local structure
-12,500
Generalized contour on top of Paleozoic and metamorphic rocks
Exposed pre-Mesozoic rocks
MARATHON UPLIFT
LLANO UPLIFT
TEXAS
MEXICO
OKLAHOMA
TEXAS
BREWSTER
PECOS
TERRELL
CROCKETT
VAL VERDE
SUTTON
KIMBLE
EDWARDS
REAL
KERR
KINNEY
UVALDE
BANDERA
MAVERICK
ZAVALA
MEDINA
FRIO
BEXAR
WILSON
GUADALUPE
COMAL
HAYS
TRAVIS
CALDWELL
BASTROP
LEE
WILLIAMSON
MILAM
BELL
FALLS
LIMESTONE
FREESTONE
NAVARRO
MC LENNAN
CORYELL
HAMILTON
BOSQUE
HILL
ELLIS
JOHNSON
TARRANT
DALLAS
DENTON
COLLIN
ROCKWALL
KAUFMAN
GRAYSON
FANNIN
LAMAR
DELTA
RED RIVER
BOWIE
COOKE
GILLESPIE
KENDALL
BURNET
LLANO
SAN SABA
LAMPASAS
MARSHALL
JOHNSTON
ATOKA
BRYAN
CHOCTAW
PUSHMATAHA
MC CURTAIN
PITTSBURG
LATIMER
LE FLORE
STRUCTURE CONTOURS ON TOP OF THE OUACHITA BELT IN TEXAS AND OKLAHOMA
CONFIGURATION OF THE SURFACE OF PALEOZOIC AND METAMORPHIC ROCKS
SCALE
10 5 0 10 20 30 70 MILES
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